



# 8<sup>th</sup> EUREGEO

Barcelona | Catalonia | Spain | June 15<sup>th</sup> - 17<sup>th</sup> 2015

# EUropean Congress on REgional GEOscientific Cartography and Information Systems

Geological 3D Modelling

and

Soils: functions and threats



**Proceedings**

# **8<sup>th</sup> European Congress on Regional Geoscientific Cartography and Information Systems**

Geological 3D Modelling and Soils: functions and threats

## **Proceedings**

*The articles published on this book are solely those original authors.  
No changes were made to the author's original articles.*

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## CONGRESS ORGANISATION

### PROMOTING COMMITTEE

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<b>EuroGeoSurveys:</b>	Luca Demicheli

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<b>Xavier Berástegui</b>	Cartographic and Geologic Institute of Catalonia

### Coordination:

<i>Geological 3D Modelling:</i>	Gerold Diepolder (Bavarian Environment Agency, LfU)
<i>Soils functions and threats:</i>	Luca Montanarella (Joint Research Centre- European Commission; JRC)

### Conveners:

Magdalena Bottig (Geologische Bundesanstalt Austria; GBA),  
Holger Kessler (British Geological Survey; BGS),  
Josep Anton Muñoz (University of Barcelona, Catalonia; UB),  
Panagiotis Panagos (Joint Research Centre-European Commission; JRC),  
Ana Paya Pérez (Joint Research Centre-European Commission; JRC),  
Rosa M. Poch (University of Lleida, Catalonia; UdL)

### Local Organising Committee

Carme Puig, Jorge Fleta and Eulàlia Pujal  
*Cartographic and Geologic Institute of Catalonia*



## Programme summary

June 15 <sup>th</sup> , 16:00 h		Opening Ceremony. Room A	
18:00h		Icebreaker. Garden of the congress site.	
Lecture rooms		Room B	Room C
June 16 <sup>th</sup> , 08.40h		<b>Geological 3D Modelling. Session 1. Towards a transnational geodata infrastructure.</b> <b>Block 1. From isolated applications...</b> <b>Coordinator:</b> Gerold W. Diepolder (LFU) <b>Conveners:</b> Holger Kessler (BGS) and Magdalena Bottig (GBA) <b>Chair:</b> François Robida (BRGM) and Gerold W. Diepolder (LFU)	
10.30h		Coffee break and posters	
11.00h		<b>Geological 3D Modelling. Session 1. Towards a transnational geodata infrastructure.</b> <b>Block 2: ... to cross-border interoperability</b> <b>Chair:</b> François Robida (BRGM) and Gerold W. Diepolder (LFU)	
13.00h		Lunch time	
14.30h		<b>Geological 3D Modelling. Session 2. How to integrate academic research</b> <b>Block 1. Challenges for academic research</b> <b>Coordinator:</b> Gerold W. Diepolder (LFU) <b>Conveners:</b> Holger Kessler (BGS), Magdalena Bottig (GBA) <b>Chair:</b> Holger Kessler (BGS) and Magdalena Bottig (GBA)	
16.00h		Coffee break and posters	
16.30h		<b>Geological 3D Modelling. Session 2. How to integrate academic research</b> <b>Block 2. Applications in geo hazard assessment and model visualisation</b> <b>Chair:</b> Holger Kessler (BGS) and Magdalena Bottig (GBA)	
18.30h		End of the day sessions	
20.30h		Social Dinner	
June 17 <sup>th</sup> , 08.30h		<b>Geological 3D Modelling. Session 3. From external sources to external users</b> <b>Block 1</b> <b>Coordinator:</b> Gerold W. Diepolder (LFU) <b>Conveners:</b> Gerold W. Diepolder (LFU) and Óscar Gratacós (UB) <b>Chair:</b> Gerold W. Diepolder (LFU) and Óscar Gratacós (UB)	
10.30h		Coffee break and posters	
11.00h		<b>Geological 3D Modelling. Session 3. From external sources to external users</b> <b>Block 2</b> <b>Coordinator:</b> Gerold W. Diepolder (LFU) <b>Conveners:</b> Gerold W. Diepolder (LFU) and Óscar Gratacós (UB) <b>Chair:</b> Gerold W. Diepolder (LFU) and Óscar Gratacós (UB)	
13.00h		Closing Ceremony. Room B	
13.30h		Farewell drink. Garden of the congress site	
14.00h		End 8 <sup>th</sup> EUREGEO Barcelona'2015	
		<b>Soils: Functions and threats. Session 1</b> <b>Soil Contamination</b> <b>Coordinator:</b> Luca Montanarella (JRC) <b>Convener:</b> Ana Payá- Pérez (JRC) <b>Chair:</b> Ana Payá- Pérez (JRC)	
		<b>Soils: Functions and threats. Session 1. Soil Contamination (Continuation)</b> <b>Selected Posters presentation</b> <b>Chair:</b> Ana Payá- Pérez (JRC)	
		<b>Soils: Functions and threats. Session 2.</b> <b>Soil Maps</b> <b>Coordinator:</b> Luca Montanarella (JRC) <b>Convener:</b> Rosa M. Poch (UdL) <b>Chair:</b> Rosa M. Poch (UdL)	
		<b>Soils: Functions and threats. Session 2.</b> <b>Soil Maps (Continuation)</b> <b>Chair:</b> Rosa M. Poch (UdL)	
		<b>Soils: Functions and threats. Session 3</b> <b>Soil Erosion</b> <b>Coordinator:</b> Luca Montanarella (JRC) <b>Convener:</b> Ana Payá-Pérez (JRC) <b>Chair:</b> Ana Payá-Pérez (JRC)	
		<b>Special Session EUROGEOSURVEYS</b> <b>Minerals 4EU. Stakeholders Consultation and Information Session</b>	

The poster presentations will be on display for the whole congress in the respective poster areas.

The authors of the poster presentations on Soils are kindly asked to bring a pdf image of them to be projected and discussed in the Room C. See the detailed programme oral presentations, next pages

## Detailed programme oral presentations

### Tuesday, June 16<sup>th</sup>, Morning. Oral presentations

08.50-13.00	<b>Room B. Geological 3D Modelling. Session 1. Towards a transnational geodata infrastructure</b> Coordinator: Gerold Diepolder (LfU) Conveners: Holger Kessler (BGS), Magdalena Bottig (GBA)		
08.50-10.30	<b>Block 1. From isolated applications .....</b> Chair: François Robida (BRGM) and Gerold W. Diepolder (LfU)	<b>08.50-13.00</b>	<b>Room C. Soils: Functions and threats. Soil Contamination</b> Coordinator: Luca Montanarella (JRC) Convener: Ana Payá- Pérez (JRC)
08.50-09.00	<i>Welcome and introduction to the Session</i> <b>Gerold Diepolder (LfU); Holger Kessler (BGS), Magdalena Bottig (GBA), François Robida (BRGM)</b>	08.50-09.00	<i>Welcome by the Convener and introduction to the Session</i> <b>Ana Payá – Pérez.</b> Joint Research Centre – Ispra, Italy
09.00-09.15	<i>3D image of the Empordà Basin (NE Spain) obtained from rescued seismic data</i> <b>Beatriz Benjumea;</b> Astrid Ribot; Albert Macau; Anna Gabas; Ricard Puig, Sara Figueras	09.00-09.30	<b>Key note speech: Revision of soil indicator CS1015 for the management of contaminated sites in Europe</b> <b>Ana Payá Pérez-</b> Joint Research Centre – Ispra, Italy
09.15-09.30	<i>Updating the 3D geological model of Catalunya v. 1.0: the northern sector of the Neogene Empordà Basin (NE Catalunya)</i> <b>Oscar Gratacós;</b> Laura Serra; Josep Anton Muñoz; Xavier Berástegui; Joana Mencós	09.30-09.50	<i>Cartographic tools to support the management of contaminated sites: the “Pedogeochemical maps at 1:250,000 scale” of Emilia-Romagna Region</i> <b>Nazaria Marchi,</b> Regione Emilia-Romagna-Servizio geologico sismico e dei suoli
09.30-09.45	<i>3D Geological modeling of the coastal area in Emilia-Romagna, ITALY</i> <b>Lorenzo Calabrese;</b> Luisa Perini; Samantha Lorito; Paolo Luciani; Alberto Martini; Paolo Severi; Annamaria Correggiari; Alessandro Remia	09.50-10.10	<i>Geochemical mapping and environmental risk assessment of contaminated soils associated with mining activity: El Campillo, (Huelva province, Spain).</i> <b>Maria Clara Zuluaga,</b> Università degli Studi di Napoli Federico II. Napoli, Italy
09.45-10.00	<i>Calculating CO2 storage capacity in an unconformity trap formed at the backlimb of a fault-propagation fold: The Mar Cantabrico-E1 detritic reservoir (Cantabrian Margin, Spain)</i> <b>Jesús García-Senz;</b> Adolfo Maestro; Fernando Bohoyo; Fernando Fernández-Sáez; María Najarro; José Luis García-Lobón; Ana Isabel López-Barrera; Marta Domínguez; Isabel Suárez	10.10-10.30	<i>Elevated geogenic contents – exemplified for arsenic in soils of Bavaria</i> <b>Bernd Schilling,</b> Bavarian Environment Agency, Germany
10.00-10.30	<b>General discussion</b>		
10.30-11.00			
<b>Coffee break. Posters</b>			
11.00-13.00	<b>Block 2: ..... to cross-border interoperability</b> Chair: François Robida (BRGM) and Gerold W. Diepolder (LfU)	<b>11.00-13.00</b>	<b>Room C. Soils: Functions and threats. Soil Contamination. Selected Posters presentation</b>
11.00-11.10	<i>Introduction to the Block 2</i> <b>François Robida (BRGM) and Gerold W. Diepolder (LfU)</b>	11.00-11.10	<i>Introduction to the selected posters presentations</i> <b>Ana Payá – Pérez</b>
11.10-11.25	<i>A 3D Model of the North German Basin – Challenges and approaches</i> <b>Christian Müller,</b> Gabriela von Goerne, Björn Zehner, Stephan Steuer, Fabian Jähne-Klingberg, Stefan Knopf, Gesa Kuhlmann, and Project Group	11.10-11.20	Selected poster presentation 1
11.25-11.40	<i>Cross-border geophysical and geological models between Romania and Ukraine in the Low Danube area</i> <b>Lucian Besutiu;</b> Mykhailo Orlyuk; Luminita Zlagnean; Andriy Romanets; Ligia Atanasii; Iryna Makarenko	11.20-11.30	Selected poster presentation 2
11.40-11.55	<i>H3O – a (hydro)geological model that opens the frontier</i> <b>Ronald Vernes ;</b> Jef Deckers ; Griet Verhaert and Erik Heskes	11.30-11.40	Selected poster presentation 3
11.55-12.10	<i>A team collaboration tool and platform to share 3D geomodels</i> <b>Paul Gabriel ;</b> Jan Giezel and Helmut Schaeben	11.40-11.50	Selected poster presentation 4
12.10-12.25	<i>The limits of interoperability – model fusion needs more than technical solutions</i> <b>Robert Pamer</b> and the GeoMol Team	11.50-12.00	Selected poster presentation 5
12.25-13.00	<b>General discussion and conclusions</b>	12.00-13.00	<b>General discussion and conclusions</b>
13.00-14.30			
<b>Lunch time</b>			

## Tuesday, June 16<sup>th</sup>, Afternoon. Oral presentations

	Room B. Geological 3D Modelling. Session 2. How to integrate academic research Coordinator: Gerold Diepolder (LFU) Conveners: Holger Kessler (BGS), Magdalena Bottig (GBA)	14.30-18.30	Room C. Soils: Functions and threats. Session 2. Soil Maps. Session sponsored by Coordinator: Luca Montanarella (JRC) Convener: Rosa M. Poch (UdL)
14.30-16.00	<b>Block 1. Challenges for academic research</b> Chair: Holger Kessler (BGS) and Magdalena Bottig (GBA)	14.30-16.00	<b>Soil Maps</b> Convener: Rosa M. Poch (UdL)
14.30-14.35	<i>Introduction to the Session 2.</i>	14.30-14.40	<i>Welcome by the Convener and introduction to the Session 2</i> <b>Rosa M Poch</b>
14.35-14.50	<b>Basement characterization and cover deformation of the Linking Zone (NE Spain) from 2.5D and 3D geological and geophysical modelling</b> <b>Concepción Ayala</b> , Esther Izquierdo-Llavall, Félix Rubio, Emilio Pueyo, Antonio Casas, Belén Oliva-Urcia, Adriana Rodríguez-Pintó, Carmen Rey-Moral and José F. Mediato	14.40-15.10	<b>Key note speech: Mapping soil organic carbon content using spectroscopic data.</b> <b>Marcela Rial Tubiño</b> ; Antonio Martínez Cortizas, and Luis Rodríguez Lado.
14.50-15.05	<i>Results of a academic research for use in the daily business of a Geological Survey – Case study</i> <b>Lower Main Plains (Germany)</b> <b>Hannah Budde</b> , Christian Hoeselmann, Rouwen Lehné, Heiner Heggemann.	15.10-15.30	<i>Hydric soils: Mapping and classification</i> <b>Angel Marqués-Mateu</b> ; Héctor Moreno-Ramón and Sara Ibáñez-Asensio
15.05-15.20	<b>3D geological modelling in Canada: Challenges and opportunities for academic research</b> <b>Martin Ross</b> ; Michel Parent; Amanda Taylor; Aaron Bustard and Tyler Hodder		
15.20-15.35	<i>Steps towards a 3D model of the German Baltic Sea area – collaboration with academic research in the USO project</i> <b>Karsten Obst</b> ; André Deutchmann; Elisabeth Seidel and Martin Meschede	15.30-15.50	Assessing soil biodiversity and soil biological activity in europe <b>Ece Aksoy</b> ; Ciro Gardi; Geertrui Louwagie; Christoph Schröder and Mirko Gregor
15.35-15.50	<i>Multi-institutional co-operations in geosciences as a key for supporting both sustainable land-use management and an efficient daily business of a Geological Survey</i> <b>Rouwen J. Lehné</b> , Hannah Budde and Christian Hoeselmann	15.50-16.10	<b>General discussion</b>
15.50-16.10	<b>General discussion</b>	16.10-16.30	<b>Coffee break. Posters</b>
16.10-16.30	<b>Coffee break. Posters</b>	16.30-18.30	<b>Soil Maps (Continuation)</b> Convener: Rosa M. Poch (UdL)
16.30-16.35	<b>Block 2. Applications in geo hazard assessment and model visualisation</b> Chair: Holger Kessler (BGS) and Magdalena Bottig (GBA)	16.30-16.35	<i>Welcome by the Chair</i> <b>Rosa M. Poch</b>
16.35-16.50	<i>Introduction to the Block 2</i> <b>Holger Kessler (BGS) and Magdalena Bottig (GBA)</b>	16.35-16.55	<i>Apparent soil electrical conductivity and ndvi to delineate management zones in fruit orchards</i> <b>José A. Martínez-Casasnovas</b> , Alexandre Escolá, Manel Ribes, Jaume Arnó and Joan R. Rosell-Polo
16.50-17.05	<i>3D paleoseismology to obtain net slip-rates for lateral strike slip faults with a reverse component</i> <b>Marta Ferrater</b> ; Maria Ortuño; Eulalia Masana; Hector Perea; Stephane Baize; Raimon Pallás; Eduardo García-Meléndez; Anna Echeverría; José J. Martínez-Díaz; Tom Rockwell	16.55-17.15	<i>The soil map of the Institut Cartogràfic i Geològic de Catalunya</i> <b>Emilio Ascaso-Sastrón</b> , Marc Vicens-Ferrer; Patricia López-Villalba and Ignasi Herms-Canelles
17.05-17.20	<b>3D geological model of the central Po plain (Italy): subsurface geopotentials vs geological hazards</b> <b>Francesco E. Maesano</b> , Chiara D'Ambrogio, Fernando Ferri, & the Italian GeoMol Team	17.15-17.35	<i>Soil mapping in the Bavarian Alps – An experience report</i> <b>Robert Traidl</b>
17.20-17.35	<i>Toward open data for borehole database and 3D geological modelling for seismic hazard assessment in the coastal plain adjacent to the Tokyo bay, Japan</i> <b>Katsumi Kimura</b> , Masahiro Ooi, Yuki Hanashima and Tsutomu Ochiai	17.35-17.55	<i>Tools to facilitate the use of soil maps in Emilia-Romagna region (Italy)</i> <b>Paola Tarocco</b>
17.35-17.50	<i>Communicating 3D Geological Models – Innovative techniques of visualization</i> <b>Peter Wycisk &amp; Lars Schimpf</b>	18.15-18.30	<i>Soil analysis and soil mapping</i> <b>Miquel A Aran - Eurofins Agroambiental, S.A.</b>
17.50-18.30	<i>New technologies of 2-D &amp; 3-D modeling for analysis and management of natural resources</i> <b>Eugenia Cheremisina</b> ; Anna Lyubimova	18.15-18.30	<b>General discussion and conclusions</b>
18.30	<b>General discussion and conclusions</b>		

End of the day sessions

## Wednesday, June 17<sup>th</sup>, Morning. Oral presentations

08.30-12.55	<b>Room B. Geological 3D Modelling. Session 3. From external sources to external users</b> Coordinator: Gerold W. Diepolder (LFU) Conveners: Gerold W. Diepolder (LFU) and Óscar Gratacós (UB)	<b>08.30-10.30</b>	<b>Room C. Soils: Functions and threats. Session 3. Soil Erosion.</b> Coordinator: Luca Montanarella (JRC) Convener: Ana Payá-Pérez (JRC)
08.30-10.30	<b>Block 1.</b> Chair: Gerold W. Diepolder (LFU) and Óscar Gratacós (UB)	<b>08.30-10.30</b>	<b>Convener:</b> Ana Payá-Pérez (JRC)
08.30-08.40	<i>Introduction to the Session 3</i>	08.30-09.00	<b>Keynote:</b> <i>Soil Degradation and International Commitment for the Protection of Soil</i> <b>Ana Payá-Pérez</b>
08.40-09.10	<b>Gerold W. Diepolder (LFU) and Óscar Gratacós (UB)</b> <b>Keynote:</b> <i>From external sources to external users: A review of geological modelling development within National Geological Surveys</i> <b>Alan Keith Turner</b>	09.00-09.20	<i>Soil erosion: from modelling to mitigation: Can conservation agriculture be a solution?</i> <b>Giampaolo Sarno et al.</b>
09.10-09.25	<i>Compilation and dissemination of a digital deep subsurface model of the Netherlands.</i> <b>Maryke den Dulk</b> ; Hans Doornbal and Johan ten Veen	09.20-09.40	<i>3D quantification method of linear erosion forms on vineyards using high resolution aerial images.</i> <b>A. Farnós Viñals</b> ; D. Noll; M. Mota, and S. Burgos
09.25-09.40	<i>3D geological information for professionals and the public – Two examples for providing target group based data sets by the State Geological Survey of Baden-Württemberg (Germany)</i> <b>Isabel Rupt</b> & the LGRB 3D-Modelling Team	09.40-09.50	Selected Poster Presentation 1
09.40-09.55	<i>New geological models from the British Geological Survey</i> <b>Steve Mathers</b> and Holger Kessler	09.50-10.00	Selected Poster Presentation 2
09.55-10.10	<i>The 3D GeoloGiro</i> <b>Francesca R. Luger</b> , Nicola Luger, Gian Vito Graziano, Piero Farabollini, Vittorio Amadio	10.00-10.10	Selected Poster Presentation 3
10.10-10.30	<b>Discussion</b>	10.10-10.30	<b>General discussion and conclusions</b>
10.30-11.00		10.30	<b>End of the session</b>
<b>Coffee break</b>			
11.00-12.55	<b>Block 2.</b> Chair: Gerold W. Diepolder (LFU) and Óscar Gratacós (UB)	11.00-12.55	<b>Room C. Special Session EUROGEOSURVEYS. Minerals 4EU</b> Chair: David Ovadia
11.00-11.10	<i>Welcome by the Chair</i> <b>Gerold W. Diepolder (LFU) and Óscar Gratacós (UB)</b>		
11.10-11.25	<i>3D geological model to support the management of urban subsurface environment: Bucharest City case study</i> <b>Irina Serpescu</b> , Constantin Radu Gogu, Mohamed Amine Boukhemacha and Dragos Gaitanaru		
11.25-11.40	<i>Preparation of Gocad-Skua models for numerical simulations</i> <b>Ines Götz</b> and Martin Herbst		
11.40-11.55	<i>A voxel model for mineral resources: Loess deposits in Flanders (Belgium)</i> <b>Tom van Haren</b> ; Chris De Groot; Roel De Koninck, Katrien De Nil	11.00-12.55	Minerals 4EU. Stakeholders Consultation and Information Session
11.55-12.10	<i>Digital Modelling of Heavy Mineral Placer Deposits for Defining of Prospects of Further Deposit Development</i> <b>Nikolay Laverov</b> , Irina Chizhova, Dmitry Khrushchov and Alexander Lalomov		
12.10-12.25	<i>GIS-based 3D geological analysis tools</i> <b>Mar Alcaraz</b> , Violeta Velasco and Enric Vázquez Suñé		
12.25-12.55	<b>Wrap-up of the 3D Sessions</b> <b>Holger Kessler / Gerold W. Diepolder</b>		
12.55	<b>End Geological 3D Modelling Sessions</b>	12.55	<b>End Special Session Minerals 4EU</b>
13.00-13.30			
13.30-14.00	<b>Room B. Closing ceremony</b>  Farewell drink		
14.00	<b>End 8<sup>th</sup> EUREGEO Barcelona'2015</b>		



## Detailed programme poster presentations

### Geological 3D Modelling

**Coordinator:** Gerold Diepolder (LfU)

**Conveners:** Holger Kessler (BGS), Magdalena Bottig (GBA), Òscar Gratacós (UB)

**Chairs:** François Robida (BRGM), Gerold W. Diepolder (LfU), Holger Kessler (BGS), Magdalena Bottig (GBA), Òscar Gratacós (UB)

Adonis Photiades and Irene Zananiri	Digital geological map of Greece in scale 1:1 000 000, harmonized to One Geology Europe
Alicia Arenillas, Ricardo Molinero, Ruxandra Nita, José F. Mediato, Jesús García-Crespo, Manuel Bernat, Silvia Cervel, Carmen Rey, Concepción Ayala, Adolfo Maestro, Fernando Bohoyo, Carlos Marín, Esther Izquierdo-Lavall	Workflow for 3D geological modelling in CO2 storage assessment
Ana Ruiz-Constán; Carlos Marín-Lechado; Antonio Pedrera; Jesús Galindo Zaldivar and Carlos Sanz de Galdeano	3D geometry of the sedimentary infill in the southern sector of the Guadix basin (S Spain): constrain on the fault activity
Ana Sevillano; Juan A. Rodríguez and Ángel Salazar	Data model for a new digital Quaternary map of Spain 1:1,000,000
André Deutschmann; Martin Meschede and Karsten Obst	Seismic interpretation and visualisation for a 3D model in the southern Baltic Sea west of Ruegen Island as part of the USO project
Andreu Badia; Oriol Oms; José Ángel López and Eudald Mujal	3D field model of the Post-Variscan sedimentary succession at the Nogueres (Pyrenees)
Andreu Vinyoles; Pablo Rodríguez-Salgado; Oriol Oms; Eduard Remacha and Jorge Navarro	3D seismic data in hydrocarbon exploration: example from the Western Desert (Egypt)
Barbara Aldighieri; Bruno Testa and Francesca Romana Lugerì	Outreach potential of the interaction between 3D model and geological mapping on a web platform
Björn Zehner	On Building Large-Scale 3D Geological Models without Using Map Projections
Carlos Marín-Lechado; José Luis García-Lobón; Sergio Martos-Rosillo; Carmen Rey; Concepción Fernández-Leyva; Ana Ruiz-Constán; Israel Pérez-Ortiz; Antonio Pedrera and Juan Antonio López-Geta	Groundwater assessment in carbonate aquifers from 3D geological models (Alicante, SE Spain).
Christian Formato and Alessio Valente	3D Geological modelling application in a contaminated site.
David García-Sellés; Gratacos, Oscar; Muñoz, Josep Anton and Arbues, Pau	New tools for the study of high-resolution digital outcrops oriented to the 3D geological models.
Elisabeth Seidel; Martin Meschede and Karsten Obst	Interpretation and visualization of seismic and borehole data for a 3D model in the southern Baltic Sea, East of Ruegen Island (Germany) as part of the USO project
Elisenda Costa; Jorge Buzzi; Asunción Riaza; Oscar Fernandez; David García-Sellés; Anna Tardà; Vicenç Palà; Luca Pipia; Josep Anton Muñoz and Jordi Corbera	Assessing the potential of imaging spectroscopy applied to geological mapping in the Montsec area (Pyrenees, Spain)
Fabio Carlo Molinari; Giulio Torri; Alberto Martini & the Italian GeoMol team	3D temperature model of the central Po Plain (Italy) : subsurface geopotentials
Ivan Marchesini ; Michele Santangelo, Francesco Bucci and Mauro Cardinali	From the interpretation of stereoscopic aerial photographs to the morpho-structural setting
Jesús García-Crespo, Alejandro Díez-Montes, Concepción Ayala, Teresa Sánchez-García, Carmen Rey, José L. García-Lobón, Félix Bellido, Félix Rubio, José F. Mediato, Santiago Martín-Alfageme	3D modelling of Río Tinto area. New insights into its geological structure.
Jesús García-Crespo, Teresa Sánchez-García, José F. Mediato, Concepción Ayala, Carmen Rey-Moral, José L. García-Lobón, Félix Bellido, Félix Rubio, Alejandro Díez-Montes, Santiago Martín-Alfageme	3D modelling of Santa Olalla de Cala area. New insights into the Cala region
Jesús García-Senz; Adolfo Maestro; Fernando Bohoyo; María Najarro; Fernando Fernández-Sáez; José Luis García-Lobón; Ana Isabel López-Barrera; Marta Domínguez; Isabel Suárez	Combined use of cross-sections, seismic and core data to assess CO2 storage capacity and seal geometry in a triangle zone of deformation: The MC-J1 prospect (Cantabrian Margin, Spain)
Jordi Pérez-Cano; Manel Zamorano; Oriol Oms and Eduard Remacha	The Ager basin (Eocene, Pyrenees, Spain): Tidal influenced deltas 3D building
José F Mediato, Concepción Ayala, Teresa Sánchez-García, José L. García-Lobón, Félix Bellido, Félix Rubio,	3D gravity inversion of Cala mine (Ossa-Morena zone, Spain)

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Konstantin Lobanov, Sharov Nikolay, Chicherov Mikhail, Chizhova Irina	The integrated deep geodynamic 3D model of the Pechenga district (Baltic Shield)
Maik Schilling; Christoph Jahnke, Andreas Simon and Thomas Höding	Brandenburg 3D – GIS goes underground – a geological 3D model for the public
Manuel Bernat; Silvia Cervel; Ricardo J. Molinero and Jose F. Mediato	3D geological model for CO2 storage research in the Central-Eastern Iberian System (Maestrazgo Region, Teruel - Castellón, Spain)
Marc Diviu; Patricia Cabello and Miguel López-Blanco	3D facies modelling strategies in large fan-delta reservoirs and their implications in predictions. Data from Montserrat and Sant Llorenç del Munt outcropping analogues (Eocene, NE Spain)
Mario Wilhelm	From digital terrain model to shaded relief – practical examples from the Bavarian Environment Agency
Michele Santangelo, Ivan Marchesini; Francesco Bucci and Mauro Cardinali	3D-modelling of lithological boundaries from aerial photo-interpretation data.
Mikhail Finkelstein, Dmitriy Drovninov, and Maxim Churilin	Three-dimensional geological modelling with GIS integro use
Miquel Vilà; Pau Torrades; Roser P ; David Albalat and Ona Monleon	The role of 3D modelling in the urban geological map of Catalonia
Montse Colomer; Ignasi Herms; Georgina Arnó and Victor Camps	Application of 3D modelling for groundwater management around the Cardona diapir
Oleg Mironov, Irina Galitskaya and Irina Pozdnyakova	Hydrogeological windows map based on 3D geological model
Oriol Oms and Jordi Pérez-Cano	Combined surface geology and well data: 3D understanding of thick evaporite formation in the Eocene Ebro basin (Manresa - Artés area, Catalonia, Spain).
Pablo Rodríguez-Salgado; Andreu Vinyoles; Oriol Oms; Eduard Remacha and Jorge Navarro	Regional tectonic framework, structure and evolution of the Alamein basin (western desert, Egypt) – inferences from 3D onshore reflection seismic data
Sascha Görne and Ottomar Krentz	Cross border 3D modelling - challenges and results of a transnational geothermal project
Vlad Codrea; Mihai Dumbravă; Alexandru Solomon; Márton Venczel; Cristina Fărcaș and Ovidiu Barbu	A 3D database: a way to preserve detailed images of the terrestrial latest Cretaceous geological heritage in Transylvania (Romania)

## Detailed programme poster presentations

### Soils: Functions and threats

**Coordinator:** Luca Montanarella (JRC)

**Conveners:** Ana Payá- Pérez (JRC) and Rosa M. Poch (UdL)

**Chairs:** Ana Payá- Pérez (JRC) and Rosa M. Poch (UdL)

<b>Soils: Functions and threats. Soil contamination</b>	
<b>Coordinator:</b> Luca Montanarella	
<b>Convener:</b> Ana Payá-Pérez	
Ana Sevilla-Perea; María C. Romero-Puertas and M <sup>a</sup> Dolores Mingorance	Effect of compost and bottom ashes on metal S and As release from contaminated soils: a leaching column study
Ana Sevilla-Perea; María C. Romero-Puertas M <sup>a</sup> Dolores Mingorance	Modelling agrochemical properties and hazardous element availability of a multielement-contaminated soil amended with wastes
Chengkai Qu, Xinli Xing, Stefano Albanese, Angela Doherty, Huanfang Huang, Annamaria Lima, Shihua Qi, Benedetto De Vivo	Spatial and seasonal variations of atmospheric legacy and current-use pesticides in central China: regional source vs. long-range transport and air-soil exchange
Claudia Campanale, Valeria Ancona and Vito Felice Uricchio.	Assessment of soil quality restoration in a chronically polluted area treated with compost by combining different soil investigation techniques
Jose Antonio Rodríguez-Liébana; M. Dolores Mingorance and Aránzazu Peña	A kinetic study of pesticide sorption on various Mediterranean soils
Jose Antonio Rodríguez-Liébana; M. Dolores Mingorance and Aránzazu Peña	Pesticide sorption/desorption on Mediterranean soils modified by solution composition
Minolfi Giulia, Albanese Stefano, Lima Annamaria, De Vivo Benedetto	Multiscalar approach to assess the environmental geochemical risks from topsoils in the Campania Region (Italy)
Ramírez-Pérez, A.M. and de Blas, E.	Spatial variability of Cu in surface sediments of Ria de Vigo
Ramírez-Pérez, A.M. and de Blas, E.	Preliminary study of chemical forms of Pb in sediments of San Simon bay (NW, Spain)
Ramón Aznar, Beatriz Albero, Consuelo Sánchez-Brunete, José L. Tadeo	Analysis of pyrethroid and organochlorine insecticides in soil.
Teresa Balvis; Francesco Muntoni and Roberto Rizzo	Remote sensing in the study of the contaminated areas
Uwe Geuß; Edzard Hangen and Bernd Schilling	Hand-held XRF – a contribution to improve soil sampling strategy?
<b>Soils: Functions and threats. Soil maps</b>	
<b>Coordinator:</b> Luca Montanarella	
<b>Convener:</b> Rosa Maria Poch	
Carmela Rezza, Stefano Albanese, Annamaria Lima, Robert Ayuso, Benedetto De Vivo	Geochemical characterization, isotopic approach and environmental risk assessment in the Domizio Flegreo and Agro Aversano area (Campania region).
Concepción Paredes; Xavier Barber; Antonio Marín-Martínez; María Ángeles Bustamante; M <sup>a</sup> Dolores Pérez-Murcia; Aurelia Pérez-Espinosa; Enrique Agulló; D. Aguilar and Raúl Moral	Hierarchical Bayesian spatial modelling to identify and map spatial variations of soil properties in vitivinicultural zoning studies
David López Lluch; Damián Aguilar Morales and José Antonio Marín – Martínez,	New technologies for delineating and classifying productive areas in the wine sector
Ece Aksoy; Ciro Gardi; Geertrui Louwagie; Christoph Schröder and Mirko Gregor	Assessing soil biodiversity and soil biological activity in Europe
Emilio Ascaso-Sastrón, Marc Vicens-Ferrer; Patricia López-Villalba and Ignasi Herms-Canellas	The soil map of the Institut Cartogràfic i Geològic de Catalunya
Emilio Ascaso-Sastrón; Patricia López-Villalba; Marc Vicens-Ferrer and Ignasi Herms-Canellas	Some soil quality indicators of the soils of Catalonia
Francesca R. Lugerì, Nicola Lugerì, Barbara Aldighieri, Gianluigi Giannella; Bruno Testa	Soils, GIS and wines
Horea Bedeleian; Vlad Codrea; Ovidiu Barbu; Cristina Fărcaș and Alexandru Solomon	Regional soil distribution on the western side of the Hațeg basin and possible relationships of soils with parent rocks
Kateřina Freyerová and Luděk Šefrna	Soil Organic Carbon Quantification in Podzol Subsoil as an Attempt To Refine Soil Carbon Inventories in the Czech Republic
José A. Martínez-Casasnovas, Alexandre Escolà, Manel Ribes, Jaume Arnó and Joan R. Rosell-Polo	Apparent soil electrical conductivity and NDVI to delineate management zones in fruit orchards
Marcela Rial Tubío; Antonio Martínez Cortizas and Luis Rodríguez Lado	Mapping soil organic carbon content using spectroscopic data
Paola Tarocco	Tools to facilitate the use of soil maps in Emilia-Romagna Region (Italy)
Robert Traidl	Soil mapping in the Bavarian Alps – An experience report
Slobodan Miko; Ozren Hasan; Martina Šparica Miko; Andreja Steinberger; Helena Čučuzović; Josip Halamić	Spatial distribution of topsoil organic carbon in Croatia
<b>Soils: Functions and threats. Soil erosion</b>	
<b>Coordinator:</b> Luca Montanarella	
<b>Convener:</b> Ana Payá-Pérez	
Demetrio Antonio Zema, Giuseppe Bombino, Pietro Denisi, Diego Fortugno, Santo Marcello Zimbone	Erosion modelling by wepp in plots treated with solar-dried citrus peel
Emanuele Giaccari; Giuseppe Spilotto;	Protection works against the erosion of the coasts near to Torre Ovo in Campomarino di Maruggio (Ta)
Igor Boni, Matteo Giovannozzi; Paolo F. Martalò and Federico Mensio.	Soil erosion assessment in Piedmont: A territorial approach under the rural development program.



## STATEMENT OF THE ORGANIZING COMMITTEE

Antoni Roca, Xavier Berástegui, Claus Kumutat, Roland Eichhorn, Michela Grandi, Raffaele Pignone, Luca Montanarella and Luca Demicheli

Twenty-three years ago, in 1992, the Geological Surveys of Emilia-Romagna, Catalonia and Bavaria initiated first informal operational contacts which, two years later, resulted in the organisation of the “1st Congress on Regional Geological Cartography and Information Systems”, which took place in Bologna in June 1994.

That congress focused on the role of the Geological Surveys, both at Regional and National levels, in the light of the Principle of the Subsidiarity. Approaches, experiences and working results in the field of applied geosciences, especially on the Geological Map, the basic mission of all the Geological Surveys, and –at that time- its incipient, but promising, connection to the Information Systems, were discussed. The fact that that first congress was attended by some 700 Earth Scientific and Technicians from 29 countries is indicative of its success.

Among the specific conclusions of the first congress, the importance of the applied scientific, geological knowledge of the physical constitution of the territory, as a surface and subsurface continuum, and the importance of this knowledge for the human activity and for the other forms of life organised in their respective ecosystems, must be emphasized.

As a general conclusion, the roundtable agreed a biennial or triennial frequency for the next congresses, with the aim to serve as a meeting point in which the Regional and the National Geological Surveys, and other interested organisations, could show the results of their works at a technical level.

Following that agreement, the next meetings were organised in Barcelona (1997), Munich (2000), Bologna (2003), Barcelona (2006), Munich (2009), Bologna (2012), and the eighth edition is now being held in Barcelona.

Since the already distant times of Bologna 1994, a lot of amazing transformations in politics, in society and in science and technology have occurred. Most of them have been recorded by the develop-

ment of this series of congresses, as it is evidenced by the subheadings of the consecutive editions:

- Regionalism at European scale, geological maps and information systems (Bologna, 1994).
- The four basic functions of a Geological Survey, the specificities in the application of the geological information and the need for creating integrated geological information systems (Barcelona, 1997).
- The role of geoscience and their instruments for a sustainable development (Munich, 2000). During that congress, the initial three European Regions, aware of the importance of the cooperation with all the European Geological Surveys, and of the importance of the Soils as a basic resource for the humankind, established the necessary relations with EuroGeoSurveys (EGS) and with the European Soil Bureau of the European Commission of the Joint Research Centre (JRC), so the Secretary General of EGS and the Head of European Soil Bureau joined the Scientific Committee.
- The “Geological information for the spatial planning” (Bologna, 2003) sub headed the Fourth congress. For the first time there were sessions on Soils, both specific and regarding its relation with the Geology. The cooperation of Bayern, Emilia-Romagna and Catalunya was formalized in 2004 with the signature of a joint agreement by the responsible Regional Ministers.
- Earth and Water was the subhead for the Fifth congress (Barcelona, 2006). A wide and integrative range of themes related the diverse elements of the solid Earth, from surficial and groundwater to soils; from geological hazards to geological heritage; from coastal specific issues to the geology of the urban areas. Moreover, 2006 was the year of INSPIRE, so the congress organized a round table with the

title “European Geological Surveys preparing for INSPIRE /Geoscientific Information and Knowledge in Support of E.U. policy making” with the participation of the representatives of the European Commission.

- The Sixth congress (Munich, 2009) had the subhead of “Earth and Man” and was included in the International Year of the Planet Earth as one of the final events of that global initiative. As a major result of the 6th EUREGEO, the Scientific Committee agreed in cooperate for the next three years on a few issues of increasing importance: Geothermal energy, Geohazards and Soil conservation, to which was added the Geological Heritage.
- Three years ago, with the subheading of “Sustainable Geo-Management”, the Seventh congress (Bologna, 2012) was devoted to the aforementioned thematic issues. That congress was hold under an environment strongly influenced by the earthquake crisis which, with a main shock of MI 5.9 on May 20<sup>th</sup> and a second shock of MI 5.8 on May 29<sup>th</sup>, affected the Emilia-Romagna during the weeks previous to the congress and produced 27 casualties. The Organising Committee reiterates its condolences to the Emilia-Romagna authorities. Among the general conclusions of Bologna’2012, the Organizing Committee stated that the participation to this conference

“should be more-oriented towards the stakeholder community relevant to geology and geoscientific information and more-oriented towards the general public introducing some new formats of the conference for the future editions”. These sentences summarize two concepts: Innovation and Usability.

Following the aforementioned recommendation, this Eighth edition is subhead “Geological 3D Modelling and Soils: functions and threats” and want to reflect the increasing importance of these two major applied geoscientific issues. The Eighth EUREGEO, Barcelona’2015, supports the celebration of the International Year of Soils, declared by the General Assembly of the UN, and it is being held under the auspices of the recently founded Cartographic and Geologic Institute of Catalonia (2014), to whom the Organising Committee wish to express its acknowledgement.

The conclusions to be reached in this meeting should promote and encourage the integration of the geological and soil services into the society, which they serve. The Scientific Committee and the Local Organising Committee, have the pleasure to welcome all participants to Barcelona. Have a fruitful conference and a pleasant stay in the capital of Catalonia!

Barcelona, June 15th, 2015

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**Spatial and Seasonal Variations of Atmospheric Legacy and Current-use Pesticides in Central China: Regional Source vs Long-range Transport and Air-soil Exchange**

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## **GEOLOGICAL 3D MODELLING - ORALS**





## GIS-BASED 3D GEOLOGICAL ANALYSIS TOOLS

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**KEY WORDS:** 3D geological models, GIS, groundwater models

### INTRODUCTION

Hydrogeological models constitute an essential tool for a reliable water management, allowing us to conceptualize, identify and quantify the hydrogeological processes.

Geological models of aquifers used for groundwater modelling are often simplistic approximations of real aquifer geometry and spatial variability. The representation and analysis of the geological architecture are often made on a 2D basis (Gàmez, 2007). However, 3D analysis and modelling is necessary to represent the heterogeneity of the aquifers in the three dimensions of the space.

The improvements of 3D geographic information systems (GIS) with query functionality and data management tools have considerably enhanced our ability to characterize subsurface conditions (Pollock et al., 2012). Nevertheless, further procedures may be improved especially for the management, visualization and retrieval of detailed geological data and hydrogeological parameterization in a 3D GIS environment.

This paper presents a software platform (HEROS 3D) that integrates a spatial database and a set of tools and methodologies developed in a 3D GIS environment with the aim of facilitating: (1) the query and visualization of 3D geological data and (2) the development of 3D geological models.

The presented work forms part of a wider ongoing framework for the facilitation of detailed hydrogeological modelling that include further hydrogeological (HYYH), hydrochemical (QUIMET) and geological (HEROS) GIS-based analysis tools. This set of analysis tools was developed as an extension of two dimensional ArcMap environment (ArcGIS;ESRI) and are represented by different toolbars. These instruments are described in Velasco et al., 2012, Velasco, 2013 and Velasco et al., 2014.

HEROS 3D complements and extends the capabilities and functionalities (adding further 3D analysis tools) of these tools.

### 3D GIS-BASED PLATFORM

HEROS 3D is composed of a geospatial database and a set of tools facilitating 3D geological analysis and interpretation.

The geospatial database follows the Personal Geodatabase structure provided by ArcGIS (ESRI). It is composed of different datasets that store a variety of key spatial and non-spatial data necessary for a complete geological and hydrogeological study. The main components include hydrological, hydrogeological, hydrochemical, geophysical and geological feature. Regarding the last one, the database allows us to store an accurate and very detailed geological description (e.g. lithology, fossils contents, geotechnical properties, etc.) that can be generalized and up-scaled. In order to ensure the standardization and the harmonization of the data, several code lists (e.g. list of lithology, age, etc.) were created taking into account standard guidelines such as INSPIRE (INSPIRE 2013).

In addition the geometry and attributes of the different interpretation derived of the data stored in the database are also stored separately to allow additional interpretation and to act as framework for a new project.

The set of 3D geological analysis tools were developed as an extension to the ESRI ArcScene environment, which is the 3D module of ArcGIS 10X software package. They were created with ArcObject, and they were programmed in Visual Basic using the Visual Studio (Microsoft) environment (see Fig.1).

These analysis instruments cover a wide range of methodologies for visualizing, querying and interpreting geological data in a 3D environment. They include, among others, different commands that enable the user to: (1) query and visualize in 3D the different geological or hydrogeological units/subunits interpreted for each borehole (creation borehole tubes); (2) create 3D surfaces (TINs) automatically for the selected units/subunits interpreted from the boreholes and recorded in the database; (3) perform further calculations with the aforementioned 3D surfaces (e.g. extension); (4) Create automatically fence diagrams.

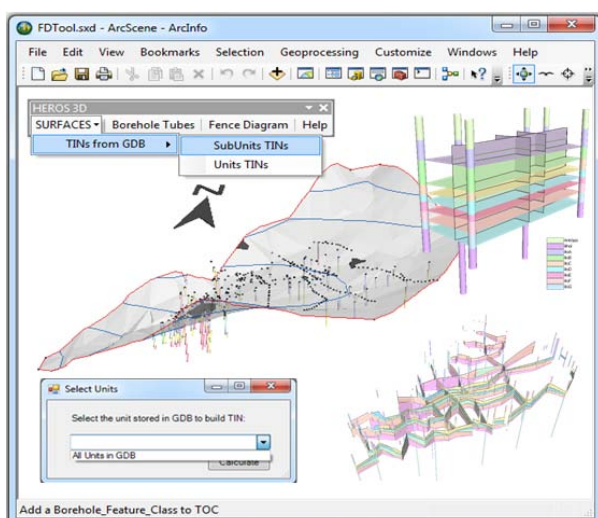


Figure 1. Sketch shows the toolbar implemented in ArcScene (ArcGIS;ESRI) and its main components. Note that some examples of 3D geological surfaces , boreholes and fence diagrams are also shown in the figure.

## CONCLUSIONS

This software platform offers a working environment for managing, querying and interpreting data in a 3D GIS environment.

The geospatial database allows us to store and manage data from most hydrogeological and geological studies. Additionally the capacity of querying and visualizing all the available information in the same 3D environment give us the possibility of integrate the geological information with other relevant data (e.g. hydrogeological data) and thus to obtain further information.

Apart from the database, the presented platform offers a great variety of automatics tools developed in ArcScene (ArcGIS;ESRI) designed to exploit the stored data. Using these tools in conjunction with the rest of the ArcGIS capabilities increase the functionality of the software, which provide a comprehensive geological analysis and a subsequent 3D geological modelization.

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## Basement characterization and cover deformation of the Linking Zone (NE Spain) from 2.5D and 3D geological and geophysical modelling.

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**KEY WORDS:** 2.5D and 3D geological and geophysical modelling, gravity, magnetics, petrophysics, balanced cross-sections, Linking Zone

### INTRODUCTION

New geological, geophysical and petrophysical information have been acquired, interpreted and presented in this work aiming to improve the understanding of the 3D Linking Zone structure (Fig. 1; see Izquierdo-Llavall et al. and references therein), an E-W-trending fold and thrust system that connects the northeastern part of the Iberian Range (WNW-ESE-striking) and the Catalan Coastal Ranges (NNE-SSW-striking). It was formed during the Alpine Orogeny and it is characterized by (1) thick-skinned tectonics, partly controlled by reactivation of faults inherited from Mesozoic times and (2) thin-skinned tectonics, affecting the cover sequences above the regional detachment levels (Triassic gypsum and shales). The present study aims to obtain a 3D model of this area through the construction of balanced geological and geophysical cross sections based on gravity and magnetic modelling. This investigation focuses on the geometry of the top of the basement and the fault's network cutting across it in order to evaluate the suitability of a potential CO<sub>2</sub> storage sites in the area.

In the Linking Zone no seismic data is available and other subsurface information is scarce. Therefore, we carried out several surveys to acquire new gravity and magnetic data as well as rock samples to define petrophysical variables needed in the geophysical modelling: A) 938 gravity stations were measured, distributed along 8 main profiles. These new stations were complemented with 1953 gravity data points from SITOPO IGME database (Fig. 1). These data were processed to obtain a Bouguer anomaly map and a residual gravity map with reasonably good coverage; B) a petrophysical survey was also carried out; the rock samples were analysed obtaining density and magnetic susceptibility. A

total of 1470 samples have been used to define the physical properties of the main lithologies

### 2.5D AND 3D MODELLING

The statistics of the physical properties are of key importance during the combined geophysical and geological modelling. Petrophysical data indicate a weak, progressive increase of mean density values from the top to the base of the stratigraphic pile with the only exception of Triassic gypsum and shales, where the lowest measurements were obtained. Densities and magnetic susceptibilities used in the modelling are shown in Table 1.

The modelling has been developed in three steps: First, a set of eight geological cross-sections based on surface geology (1:50000 IGME geological maps), structural information and data from eleven boreholes were built, improved through gravity and magnetic modelling and balanced to make them geometrically correct, consistent throughout the neighbouring sections and, therefore, closer to reality.

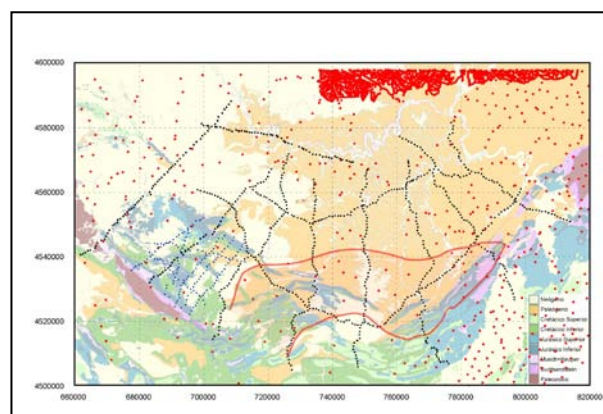


Figure 1 – Geological map with the SITOPO (red dots) and new gravity stations (black and blue dots) on top. UTM coordinates in m, Zone 30N. Red line delineates the area of interest as possible CO<sub>2</sub> storage site suggested in previous works (ALGECO2 program; García Lobón et al., 2011).

Second, the cross sections were imported in Move (by Midland Valley Exploration Ltd.) and

GeoModeller (by Intrepid Geosciences) to create a 3D geological model in accordance with all geological observations.

Stratigraphic Unit	Density	Magnetic Susceptibility
Quaternary	1.80	-
Cainozoic	2.40	60
Cretaceous	2.56	45
Jurassic	2.62	10
Upper Triassic (Keuper facies)	2.25	60
Middle and Lower Triassic (Buntsandstein and Muschelkalk facies)	2.57	60
Paleozoic	2.68	300

Table 1 – Average densities (in  $g/cm^3$ ) and magnetic susceptibilities (in  $SI \times 10^{-6}$ ) used in the modelling.

Finally, a 3D gravimetric inversion using GeoModeller was carried out to obtain the lithological horizons that also honour the petrophysical and gravimetric data.

The studied area can be divided in three structural domains: (1) the eastern margin of the Aragonian Branch, (2) the Linking Zone and (3) the transition between the Linking Zone and the Catalan Coastal Ranges. In the Aragonian Branch, the main structures partly correspond to the inversion of basement faults limiting the margins of the Oliete sub-basin, Lower Cretaceous in age. The boundaries of this basin coincide with positive residual gravity anomalies. Structures in the Linking Zone belong to the northern margin of the inverted Morella basin (Upper Jurassic-Lower Cretaceous) to the South and the thin-skinned

Portalrubio-Vandellòs thrust system to the North, both separated by a strongly deformed zone corresponding to inverted structures in the marginal areas of the Mesozoic basin. In the Catalan Coastal Ranges, faults affecting the basement are dominant. Positive residual gravity anomalies match with antiformal geometries at the front of the range and negative gravity anomalies to Plio-Quaternary basins superimposed on the Alpine compressional structure. In the foreland of the Iberian and Catalan Coastal ranges, the slightly deformed basement of the Cenozoic Ebro Basin is characterized by positive residual anomalies indicating the location of basement uplifts.

## RESULTS

The final model (Fig. 2) resulted from gravimetric inversion has allowed us to define the geometry of the top of the basement and rule out the suitability of the CO<sub>2</sub> storage site as it was initially suggested (Fig. 1). However we have identified two new structures as potential CO<sub>2</sub> reservoirs within the Triassic horizon: 1) A subsurface thrust located between the Monroyo Basin and the southern margin of the Ebro Basin and 2) a hanging-wall anticline associated to the northern thrust of the Sierra de Arcos system. Nonetheless, further investigation is needed to evaluate the quality of the seal, to check the lateral extension and closure of the structures and to calculate their volume.

## ACKNOWLEDGEMENTS

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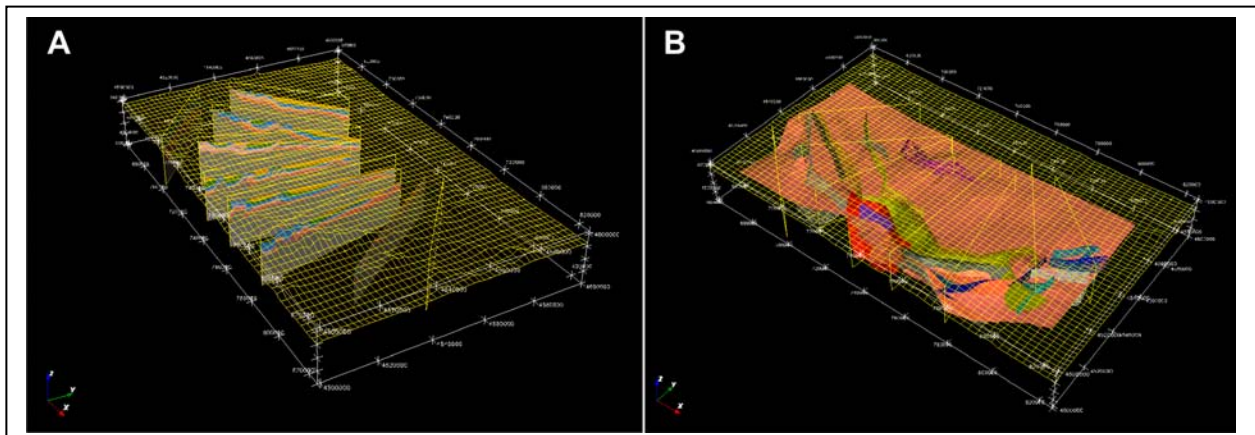


Figure 2 – A-3D view of the cross sections used as input data in the 3D model. B- Resulting geometry of the top of the basement and fault geometry

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## 3D image of the Empordà Basin (NE Spain) obtained from rescued seismic data

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**KEY WORDS:** *Seismic refraction technique, vintage seismic datasets, Neogene Basin*

### INTRODUCTION

The Empordà Basin is located in NE of Catalonia (Spain) between the Pyrenees, the Catalan Coastal Range and the Mediterranean Sea (Figure 1). Its formation and structure is relatively complex and is due to extensional movements within the Alpine orogeny, ranging from the Oligocene to the present. The fault system is characterized by NW-SE direction (Fleta et al., 1991). The basin is filled by Miocene and Pliocene continental and marine deposits. Bedrock in the study area is heterogeneous, composed of Palaeozoic metamorphic and plutonic rocks, and Mesozoic limestones and Paleogene rocks.

This basin has been the target of different geophysical studies. During the 80s, several oil companies carried out seismic reflection surveys to characterize the main deep geological structures for exploration purposes. In this work, we focus on reprocessing vintage seismic datasets using the seismic refraction technique along nine profiles crossing this Neogene Basin. The main objective is to image Neogene base, faults and characterize different bedrock lithologic units from the P-wave velocity models. To obtain a 3D image, the velocity models are represented using the opensource OpendTect software.

### DATA SETS AND REPROCESSING

Seismic reflection vintage data was acquired during 1981 and 1983 using dynamite detonated in boreholes at 20-30 m depth. During the 1981 survey, a total of 48 channels were used. The geophone group for channel was located every 60 m and the shot point interval was 120 m. On the other hand, 192 channels, a receiver spacing of 25 m and a shot point interval of 50 m was used for the 1983 field survey. Lines S23E, S29, S30, S31 and S32 correspond to the first survey while lines

UTC8301 to UTC8304 were acquired during the second survey.

The reprocessing of these datasets has been focused on first arrivals to obtain P-wave velocity models. The methodology in this work has been tuned and adapted to the dataset characteristics including the following steps. A total of 216272 P-wave arrivals were picked. Geometry and first arrival identification was done with Promax software. This information has been transformed to Rayfract data format using homemade Matlab codes. Rayfract software performs traveltimes inversion using the Wavepath Eikonal Traveltimes (WET) approach (Schuster and Quintus-Bosz, 1993). The forward modelling algorithm is the first-order Eikonal solver based on Lecompte et al. (2000). To create an initial model, Rayfract allows to obtain a velocity depth function at each station based on traveltimes curve slopes. The initial model resulted from averaging the obtained velocities over all profile stations at common depths and extending this velocity function along the profile. From the traveltimes inversion with this initial model, we derive the velocity models shown in Figure 2.



Figure 1 – Ortophoto map of the study area. Black lines show the location of the nine profiles included in this study.

## RESULTS AND INTERPRETATION

P-wave velocity models are shown in Figure 2. The maximum investigation depth covers a range from 100 m up to 1500 m. The reason for that variability can be found in the strong velocity gradients that are present in some areas reducing the ray coverage in depth.

Velocity ranges from 500 up to 5500 m/s approximately. Low velocity is related to unconsolidated or non-cemented sediments. On the other hand, high velocities correspond to cemented or consolidated materials. To establish a velocity limit in order to separate both type of materials is difficult for velocity models derived from refraction tomography. This technique is based on velocity gradients. Therefore, a sharp change of seismic velocity such as sediment/bedrock contact is depicted in a velocity model as a zone delimited by different isovelocity contours within a small range. This zone is usually related to high velocity gradient values. In order to determine the guideline to define bedrock geometry, we have compared seismic velocity and velocity gradient at same depth in some sectors of the studied lines. A relationship between high velocity gradients and a velocity range around

3500 m/s is shown. This proxy helps to identify the sediments-bedrock contact giving a maximum depth of 600-700 m in line S29 and 625-730 m in line S23E.

Bedrock velocity variation observed on these models also provides information about changes of bedrock lithological units. Finally, P-wave velocity images help to define lateral changes that can be related to faulting.

## CONCLUSIONS

This work shows the great potential of reprocessing vintage seismic data for near-surface characterization. P-wave velocity models obtained from refraction tomography technique allow to delineate bedrock geometry, to define lithological changes of bedrock and to image faulting zones. This new image of the basin will help to constrain future geological interpretations.

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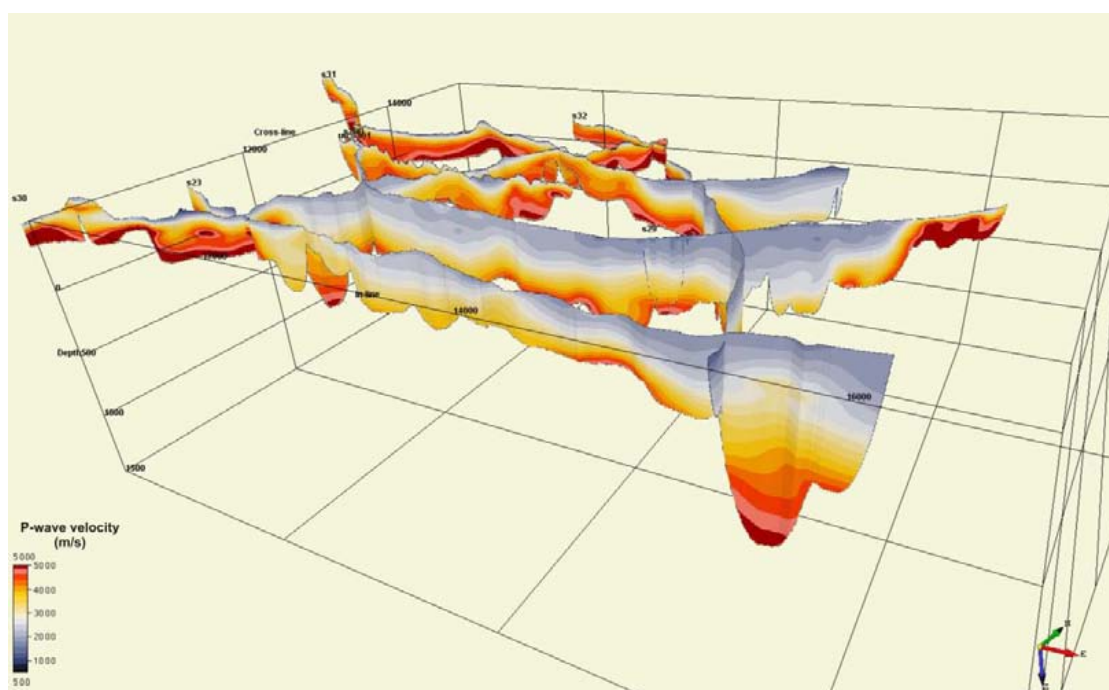


Figure 2 – P-wave velocity models resulting from applying seismic refraction tomography technique.

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## CROSS-BORDER GEOPHYSICAL AND GEOLOGICAL MODELS BETWEEN ROMANIA AND UKRAINE IN THE LOW DANUBE AREA

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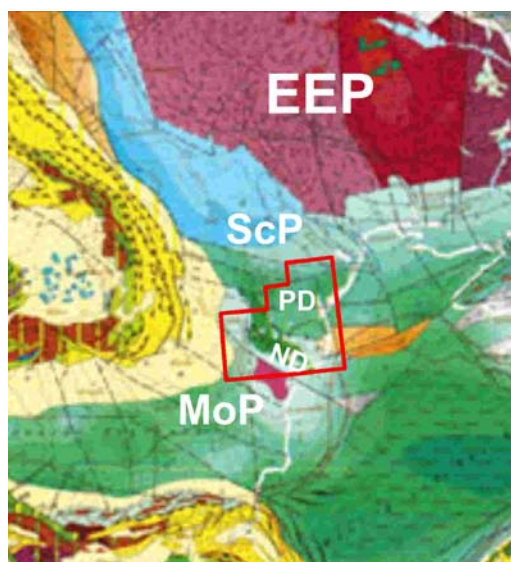
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**KEY WORDS:** *geomagnetism, gravity, geology, joint databases, modelling, Low Danube area*

### RATIONALE

**LODES** ('Low Danube area Earth's crust Structure from 3D magnetic and gravity modelling') is a joint venture of the Institute of Geodynamics of the Romanian Academy and the Institute of Geophysics of the National Academy of Sciences of Ukraine aimed at constructing consistent geological models across the state-border between Romania and Ukraine within the Low Danube area (LwDA). It represents a continuation of long-lasting collaboration between the two scientific organisations in a joint effort to build-up consistent geophysical models cross-over the state border between two countries. This study focuses on an area of special interest (Fig. 1).



*Figure 1 – Fragment from the International Tectonic Map of Europe 1:5.000.000 (Third edition). Red polygon marks location of the study area.*

The LwDA is the region where several major tectonic units join each-other. As most of its territory is covered by recent or post-tectonic deposits, geophysical methods (mainly geomagnetism and gravity) were called to help deciphering hidden junctions between Moesian Plate (MoP), North Dobrogea (ND) mobile zone, Pre-Dobrogean (PD) unit, as part of the Scythian Platform (ScP), and south-westernmost East European Plate (EEP).



## THE APPROACH

To reach the main goal of research, the project started by collecting and homogenising the available geological and geophysical information within study area. Based on a thorough review of geological and geophysical works previously performed at both sides of state-border (e.g. Besutiu et al., 2000; Nechaeva et al., 2002; Orlyuk et al., 2013), joint, GIS-compatible computer databases (e.g. topography, geology, airborne and ground magnetics, seismics, rock properties) have been designed and achieved.

All kind of stored data have faced consistency problems due to the different national standards currently used in the two countries (e.g. reference ellipsoid, projection system, stratigraphic scale, gravity system and reference density for Bouguer anomaly, geomagnetic reference field).

Consistent cross-over the state border geomagnetic models have been built up based on previously obtained national airborne geomagnetic maps, to which ground magnetic surveys, jointly conducted by Ukrainian and Romanian researchers, added new data for filling up the "white spots" on Ukrainian aeromagnetic map. Data consistency was provided by a cross-border

joint reference network and upward continuation of all the data to same altitude. Higher order derivative maps reveal no significant gradients along the state-border, thus advocating for a good quality of the merging operation.

The consistency of gravity models could be partly secured only, mainly due to the Ukrainian legislation that did not allow for conducting gravity ties across the state border. First-order derivative images show slight inconsistency in gravity datum still persists along the state-border.

## DATA VALORISATION

Based on the consistent geomagnetic and gravity datasets, some new LwDA gravity and geomagnetic maps cross-over the state border between Romania and Ukraine were constructed and interpreted (Fig. 2).

Both 2D and 3D tentative interpretative models of the gravity and geomagnetic information have been obtained based on a synthetic stratigraphy scale and a joint rock physics database, under the depth constraint provided by seismic lines and deep wells located in the study area.

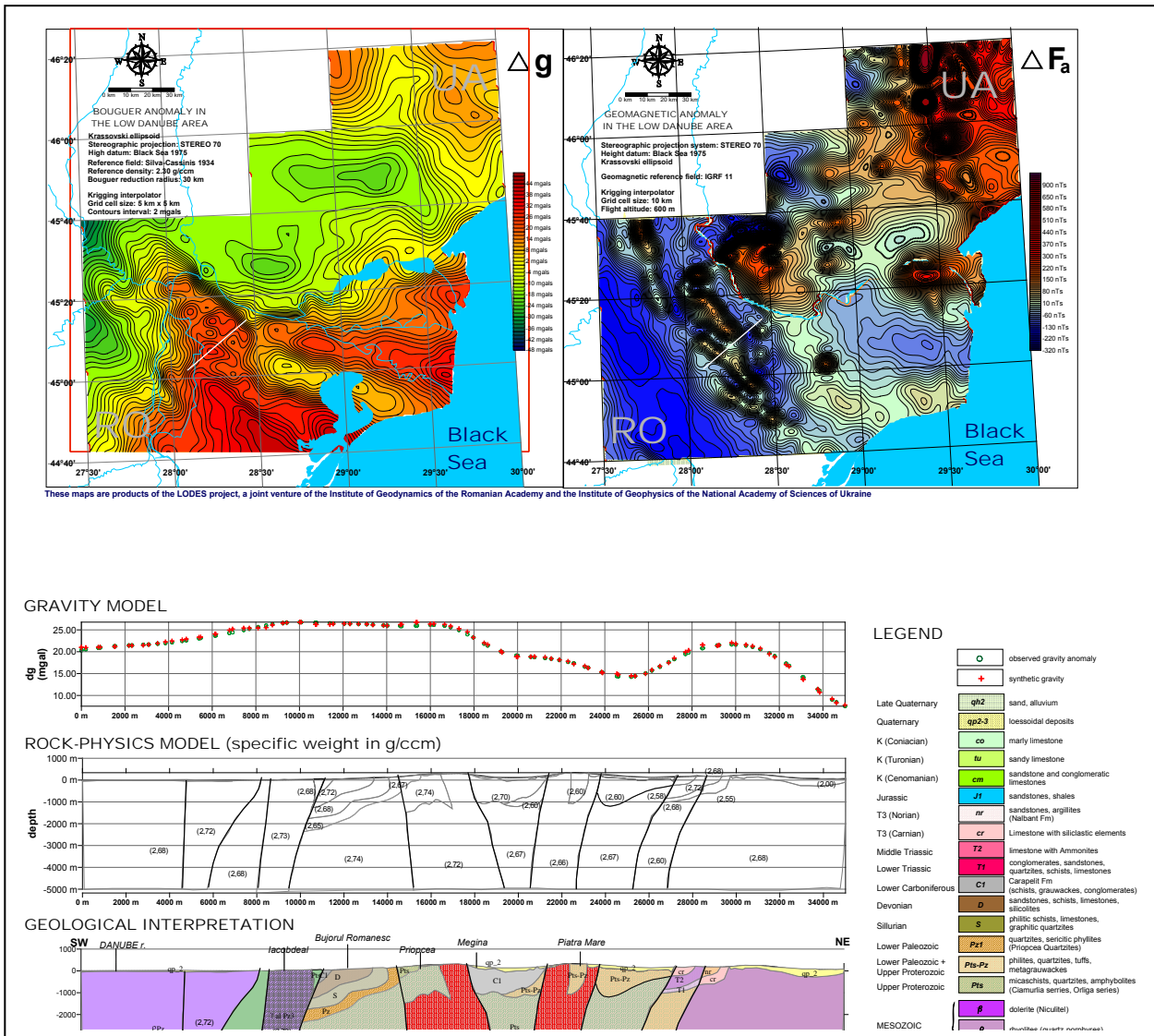


Figure 2 – Gravity and geomagnetic patterns within LwDA and tentative interpretative model across Macin Mountains

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## RESULTS OF ACADEMIC RESEARCH FOR USE IN THE DAILY BUSINESS OF A GEOLOGICAL SURVEY – CASE STUDY LOWER MAIN PLAINS (GERMANY)

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**KEY WORDS:** Lower Main Plains, 3D modelling, GOCAD, Quaternary, terrace sediments.

### INTRODUCTION

In a cooperation project between the Hessian Agency for the Environment and Geology (HLUG) and the Technical University of Darmstadt a GOCAD and GIS based geological 3D-model is being created, addressing the Cenozoic deposits of the Lower Main Plains. The Project area covers large parts of the increasing and densely populated metropolitan area Frankfurt/Rhein – Main with its high demand for near surface geo-resources like groundwater, soil and raw materials. Including the Hanau Basin, parts of the Wetterau and the Mainz Basin, as well as the transition zone of the rivers Rhine and Main at the northern end of the Upper Rhine Graben (URG) (Fig. 1), the Lower Main Plains geologically represent a Cenozoic subsidence area and host up to 600 m Quaternary and Tertiary sediments, which are the main supplier for the geo-resources mentioned above. The area is dominated by tectonic stresses caused by the uplift of the Sprenzlinger Horst and the Rhenish Shield as well as the subsidence of the northern Upper Rhine Graben (Anderle 1974, Schumacher 2002). Especially the Tertiary units are affected by tectonic offset and erosional processes, leading to uneven shape and hiatuses. Unlike point data or 2D information derived from boreholes and maps, 3D-models can help to better understand spatial geological conditions by combining and harmonizing all relevant data and visualizing these in 3D.

### DATA PREPARATION

To ensure high transparency for third parties (other geologists as well as decision makers), the model is mainly based on ‘hard’ data derived from boreholes. The main challenge in data preparation is the huge amount of layer entries and the inconsistencies regarding the stratigraphic classification in large parts of the 20,000 project relevant wells which have been provided digitally by the HLUG.

So, in a first step all wells were manually checked for quality and completeness using the method published in Lehné et al. (2013). This leads to a reduction to 9,287 wells which then were used in the modelling process. Nonetheless, more than 200,000 single layers remaining demand a (semi-) automatic analysis approach. In order to get along with the task and to objectify the stratigraphic classification, a multi-criteria approach for the derivation of the horizons has been developed, which allows a reclassification of the layers by focusing on the more objective content, i.e. the petrographic description (Budde et al. 2014).

In the process the quality checked wells first were used to identify reliable entries for Quaternary units and the Base Quaternary and to classify them regarding the underlying depositional processes. In total, nearly 70% of the queried wells contain direct information on the Base Quaternary. The remaining 30% can be used as indirect hints, assuming the Base Quaternary to be deeper. About 2,000 layers match the defined criteria to 75% and could be classified as terrace sediments. These entries were then differentiated further into the main, middle and lower terrace formation postulated by Hoselmann (2008 a and b, 2009).

### BASE QUATERNARY

Implemented and interpolated in GOCAD, the results for the Base Quaternary show a clear influence of the rivers regarding its depth level, which ranges from 48 m to about 120 m above sea level in river dominated areas and from 120 to 200 m towards the borders of the basin. The western part of the Lower Main Plains shows a generally southward dip and the highest thickness of the quaternary deposits. In the transition zone to the Upper Rhine Graben the Base Quaternary is dipping southwest towards the western master fault. Lehné et al. (2013) present similar results from the 3D-modelling project 3D\_NORG. The Base Quaternary in the eastern Lower Main Plains has a continuous depth level of about 100 m above sea level. In the southern part the surface rises up to 140-160 m above sea level.

## LOWER MAIN TERRACE FORMATION

Regarding the Bases of the Lower Main Terrace formations, the results show a northward shift of the river bed during deposition from the main to the lower terrace formation (Fig. 1), which is also described by Lang (2007). In the western Lower Main Plains the main terrace formation is

partially overlaid by sediments belonging to the middle or lower terrace formation, indicating the proceeding subsidence of the Northern Upper Rhine Graben during the Pleistocene.

In the next step of the modelling process the method will be adapted to derive target horizons of the Tertiary units.

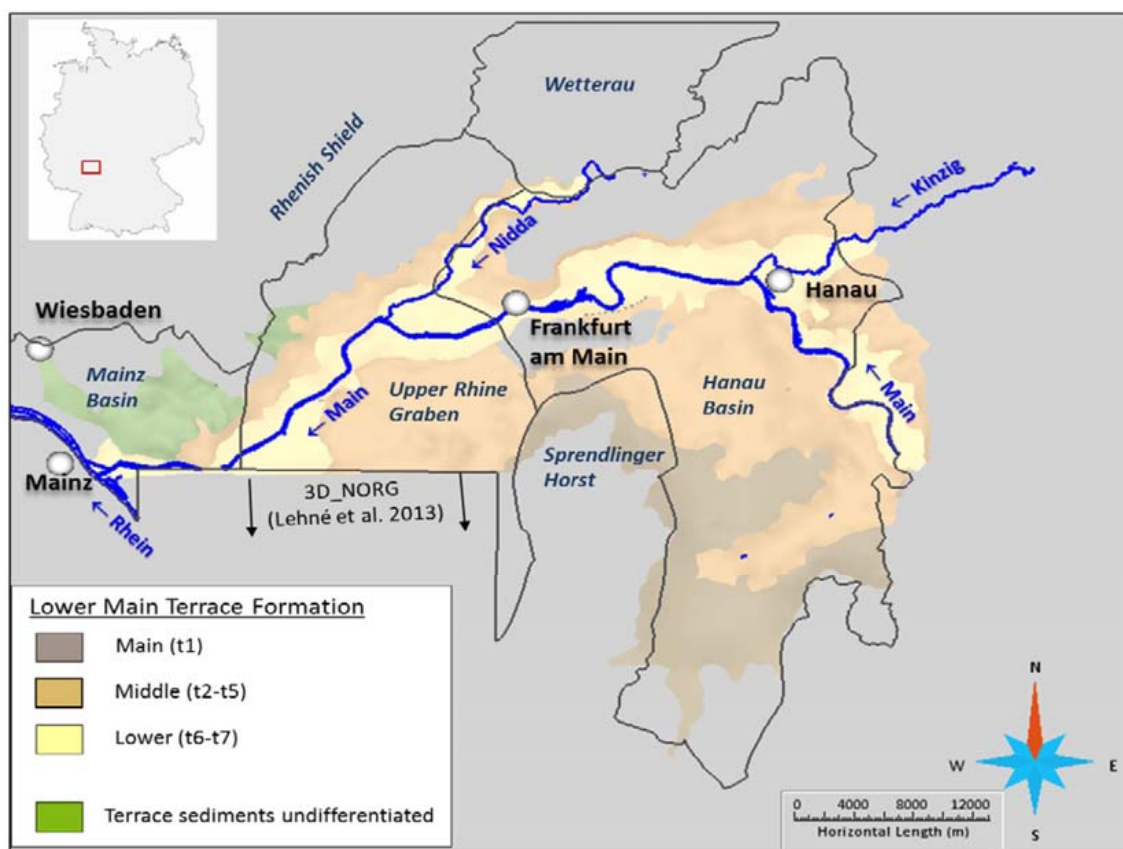


Figure 1 – Distribution of terrace sediments in the Lower Main Plains. Base horizons modelled in GOCAD.

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## 3D GEOLOGICAL MODELING OF THE COASTAL AREA IN EMILIA-ROMAGNA, ITALY

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**KEY WORDS:** geological model, Emilia-Romagna coast, information systems, land-sea correlation, numerical interpolation.

### INTRODUCTION

The study of coastal processes such as subsidence, shoreline retreat, salt water intrusion must be based on a thorough knowledge of the subsurface geology that now can be solved through the 3D modelling. Detailed three-dimensional geological models have been created thanks to the experience gained over the past twenty years and the constant implementation of databases belonging to Geological, Soil and Seismic Survey (SGSS). These models represent the stratigraphic-sedimentological framework of Quaternary succession of the coastal region of Emilia-Romagna.

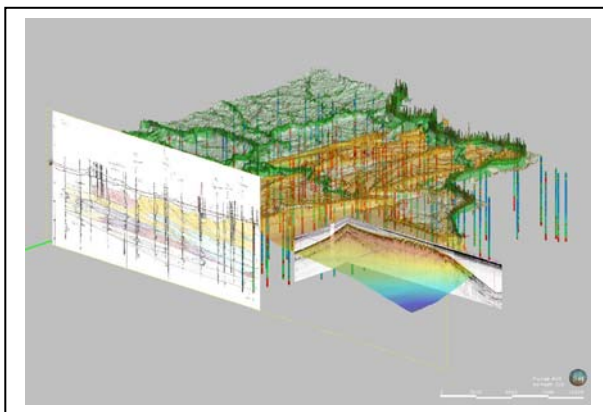


Figure 1 – Data set includes boreholes, CPTU, seismic profiles, geological cross section, DTM and geological maps.

The availability of a big amount of data within the SGSS information systems, as geological and thematic maps, high resolution digital terrain models, boreholes, wells logs and geotechnical and geophysical data, has been of fundamental importance.

The analysis of this rich data set was carried out through the 3D modeling software *Leapfrog Hydro* that allowed the integration of all data (Figure 1) and that has greatly improved the lateral-vertical reconstruction of surfaces and

geological units. This software provides a true reproduction of the stratigraphy, the generation of the volumes of the geological bodies (Figure 2) and the interpolation of numerical values within the boundaries of the same geological model.

### CASE STUDIES

In order to test the 3D modelling advantages, several studies, involving the Pleistocene-Holocene succession and dealing with diversified geological topics (hydrogeology, geotechnical, coastal dynamic, etc.) have been launched.

In the Po delta area the correlation between ground data (boreholes, CPTU) and sea-bottom data (corings and very high-resolution chirp sonar profiles, Correggiari et al., 2012) was investigated (Figure 1). As a result the reconstruction of the architecture of the different Po delta lobes from land to sea has been improved and their internal features has been defined through sedimentological analysis of lithological and seismic facies. In this sector has also been tested, with excellent results, the potential of the interpolation of the numeric data; as example, a three-dimensional distribution of the Soil Behavior Type values, calculated from the penetration tests (Robertson, 2010), was processed.

Another case study regards the phreatic coastal aquifer: the modeling approach allows to appreciate the three-dimensional geometries and internal lithological variations. In the coastal area of Lido di Classe, available piezometric data and electrical conductivity values (Bonzi et al., 2010) were processed and the distribution of fresh and salt water and the geometry of their interface were mapped, providing useful information for monitoring salt contamination of the aquifer.

Within the project of artificial water recharge of the Marecchia alluvial fan (Severi et al., 2014), was conducted an extreme detailed geological model, in order to trace the stratigraphic surfaces close to the Apennine margin. This has led to the definition of the gravelly bodies, which constitute the aquifers and the silty-clay bodies which act as aquitards. The geological model can be easily translated into a format useful for the most common hydrogeological modeling tools.

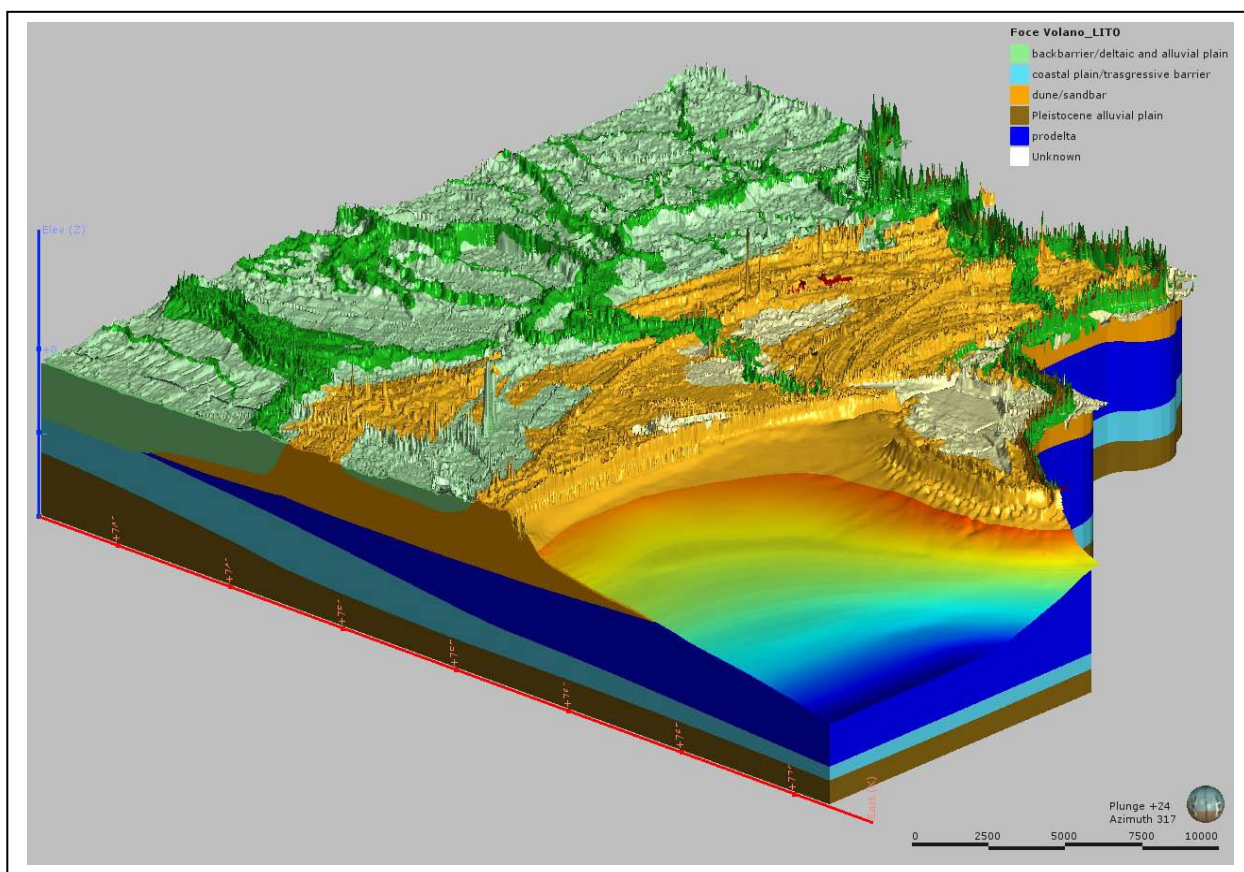


Figure 2 – Geological model of the southern margin of Po delta (Po di Volano and Po di Goro). The subsurface units (lower boundary model at -40 m msl) represent depositional environments recognized within the Holocene succession: light blue = coastal plain / transgressive barrier; blue = prodelta; orange = dunes / sandbar; light green = back barrier / deltaic and alluvial plain; in brown the Pleistocene continental substrate. On the surface: green= deltaic and fluvial channel; light brown: pond and lagoon; from orange to blue= bathymetry (0 / -20 m msl). Vertical exaggeration x150

## CONCLUSION

The results of different experimental studies, some of which are still ongoing, show that the modeling approach in the study of the geology of the Emilia-Romagna coast provides important information and a solid foundation for further studies concerning the coastal sedimentary dynamics, management of coastal risk, hydrogeology and geotechnical engineering.

The geological modeling has allowed an excellent integration of heterogeneous data, greater control and detail in the reconstruction of the subsurface geology, simplifying the stratigraphic land-sea correlation.

The outputs of numerical data processing within the geological model were encouraging and open new possibilities for the production of thematic and technical maps.

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# NEW TECHNOLOGIES OF 2-D & 3-D MODELING FOR ANALYSIS AND MANAGEMENT OF NATURAL RESOURCES

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**KEY WORDS:** *geoinformatics, 2D 3D modelling of geological and environmental processes, decision support systems.*

## INTRODUCTION

The state scientific center of Russian Federation VNIIGeosystem specializes on development scientific, methodical and technological support of programs for the effective solution of problems of environmental management. More than 50 years we are engaged in the solution of applied tasks in the field of geological studying of a subsoil, mining, environmental protection; development of software products for implementation of similar projects; carrying out educational actions in these subject domains

For ensuring technological support of research and administrative activity in the sphere of environmental management we developed a specialized modular program complex. Its components provide realization of three main stages of any similar project:

- - effective management of data and constructing of information and analytical systems of various complexity
- -complex analytical processing of spatial information and solution of expected and diagnostic tasks
- -operative visualization of data and results of researches among the Internet, creation of the situational centers of support of administrative decisions.

The special attention in developing a program complex is focused to creation of convenient and effective tools for creation and visualization 2d and

3D models providing the solution of tasks of the analysis and management of natural resources

## DECISION MAKING PROCESS SUPPORT

The interesting technological decision realized in this platform are the interface tools of the analysis of alternatives. They allow to formalize and present the analyzed problem in the form of model - a hierarchical tree of possible alternatives of its decision - to range the existing alternatives on a complex of the subjective or objective preferences defined on the basis of initial indicators (standard or situational), and to choose the best solution of an objective. In a basis of algorithmic providing this used the method of the hierarchical analysis of semistructured data, it includes various algorithms of numerical methods of the decision of systems of the equations, statistical methods and methods of situational modeling. This approach provides the deep analysis of a situation which allows to answer a number of questions, important at acceptance of a final decision, like this:

- -what contribution on final result was made by each factor or criterion;
- -how the resultant situation will change when entrance data, expert preferences, standard indicators will change;
- -what it is necessary to change for improvement of a negative situation, and so on.

## TOOLS FOR SPATIAL MODELING

The subsystem of spatial modeling which is a part of the multi-purpose geoinformation MGS server provides the solution of other, not less important aspect of problems of support of decision-making in the sphere of territorial administration - creation and the analysis of the

models provided with the spatial attached data. It include the analysis of geographical factors of possible risks when planning new objects of social and economic and production infrastructure, an assessment and the forecast of an ecological situation and emergency situations on the basis of data of expeditious monitoring of a state of environment, a choice of the most suitable arrangement of objects when developing strategy of development of the region.

The program and technological environment of spatial modeling provides creation of hierarchy of the factors defining the analyzed event or process, calculation of their spatial characteristics (intensity, usefulness, danger etc.) with use of semantic descriptions, the range scales and strict mathematical dependences, receiving the complex assessment of the analyzed properties reflecting a total picture of a state (the forecast, manifestation) events in the studied territory. The algorithmic device of the environment includes various dependences for calculation of one-dimensional, two-dimensional and three-dimensional signs of natural processes and technogenic objects. Environment includes original means of processing of classification and dispersive models, and also the tools for management of system of expert preferences and gradation of a criteria assessment of factors of model and their derivative characteristics allowing to count "on a time" the constructed model taking into account dynamics of development of a situation or the changed views of its assessment.

The main advantage of above-mentioned means of support of decision-making is use of integrated system approach to processing of diverse data, interesting algorithmic decisions, including, with use of methods of the distributed calculations, and also possibility of full integration of these tools into geoinformation platform with providing not only a local, but also remote operating mode

### **GIS FOR 2D & 3D GEOLOGICAL MODELING**

The applied geographic information system of GIS INTEGRO is developed for creation of the desktop GIS-applications focused on research projects in the field of geological studying of a subsoil and the forecast of minerals. The system contains the tools of electronic cartography, provides a wide set of algorithms and the interface

functions for carrying out mathematical, probabilistic and statistical and heuristic data processing, a construction tool of two-dimensional and three-dimensional models of a geodata on a complex of the data obtained from all levels of sounding of a terrestrial surface and deep structure.

The GIS INTEGRO tools provide all necessary stages of the geoinformation analysis:

- preparation of GIS-projects of any complexity for information support of researches and performance of analytical data processing with possibility of use of libraries of reference symbols;
- work with the main raster and vector formats, and also specialized formats of submission of geologic-geophysical data
- joint visualization of data of various spatial localization (a well – a section – the card - volume); positioning and synchronization of cursors in several windows;
- vectorization on a raster in the semi-automatic mode and object editing with support insidelayer and interlayaer topology;
- tools of a cartographical binding of rasters and vector maps with big library of projections and datum;
- programming on the built-in macrolanguage for formation of own algorithms and packages of processing.

The analytical part GIS INTEGRO includes a full range of functions of the geoinformation analysis of vector and raster data, and also have algorithmic providing for carrying out specialized processing: structural, textural and morphological analysis of fields and images; the formal analysis of quality of data on completeness and consistency; recognition of images and division into districts on a set of spatial characteristics and so forth.

On the basis of functionality of system the specialized program and technological complexes configured to the solution of specific thematic objectives are developed: data processing of geophysical shootings, forecast of mineral deposits, geological mapping etc. Interfaces of such complexes are focused on the subject expert and don't demand from the user of profound knowledge of geoinformatics. The models of a structure of subsoil plots created during analytical



researches can be published in shape web GIS of appendices with use of functionality of MGS-framework which libraries provide effective 3-D visualization of models of any complexity in the mode of remote access.

## CONCLUSIONS

The presented program complex is widely used at scientific institutes, the Russian and foreign geological companies and business. As examples of the most interesting projects in the field of modeling of the natural processes and situations realized on its basis can be allocated:

- creation of system of monitoring of dangerous petroleum wells, including model of support of decision-making on prime elimination of the most dangerous from the point of view of impact on environment
- the analysis of natural and technological hazards for a number of regions of the Russian Federation with creation of computer Internet models for an assessment and the forecast of a situation
- creation of three-dimensional models of a structure of crust on the basis of integration of geophysical, geological and space data for the solution of tasks of the forecast of fields of solid minerals and hydrocarbons for territories of the Western and Eastern Siberia.

We have a lot of experience of its application in educational process in cooperation with the leading higher educational institutions of Russia and foreign countries. We are ready to offer partners producing of projects in the field of environmental management and environmental protection, and ready software solutions for implementation of the tasks.

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# DIGITAL MODELING OF HEAVY MINERAL PLACER DEPOSITS FOR DEFINING OF PROSPECTS OF FURTHER DEPOSIT DEVELOPMENT

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**KEY WORDS:** *digital modeling, structural-lithological modeling, geological-dynamic modeling, logic-information modeling, heavy mineral placers, hybrid expert systems.*

## Introduction

The target of the paper is the presentation of theoretical basis, methods and obtained results of digital modeling for heavy minerals placers as well as defining of prospects for this methodology farther development. It is connected with need to improve methods of informational provision for researching works, aimed at involving of heavy minerals placers for the development of raw materials base of titanium, zirconium, tin, gold and other metals according to demands of pertinent industrial issues progress.

As examples of the application of various methods of digital modeling, the gold placer objects of Southeast part of the Aldan shield, titanium-zirconium deposit Centralnoe (Tambov region, Russia), titanium deposit Zlobichskoe (Ukraine) are considered.

## Theoretic Basis and Methodology

Modern version of the modeling methodology is based upon the combination of two directions: digital structural-lithological (DSL) modeling of sedimentary formations and geological-dynamical modeling of heavy minerals placers.

The methodology of DSL modeling [1] is based on the combination of three theoretic directions: geological structural analysis, system approach and general principles of computer modeling. DSL model is built as the result of computer processing of the target database, prepared on the basis of these principles. It represents the most adequate volume mapping of structural and physical characteristics of geological object reflecting the spatial distribution of different elements of its structure and composition, including mineralization characteristics, processability, etc. To develop structural-lithologic models the procedure of their construction includes such landmark tasks as: development of a hierarchical structure of the

object, the allocation of structural elements; the setting of lithological (including ore) filling of the structural elements; development of two-dimensional layout of the model; development of digital three-dimensional model, its verification; use model (derivatization, etc.).

Methodology of geological-dynamic modeling of heavy mineral placers [2] is based on the study of the dynamic mechanisms of the main stages of placer formation processes - from the mobilization in the load sources of placer-forming material to deposition in the terminal sedimentary basin.

The concrete geological-dynamic models according to the various material and genetic types at consecutive stages of geological-prospecting survey are defined:

- The method of "mass balance" is offered for creation of two-dimensional models at a prospecting-estimated stage;

- The method "diffusion-convection migration of tracer" will be used for the creation of three-dimensional models for detailed estimation of deposits.

The purpose of modeling is to build a predictive-oriented spatial (3D) model of placers in the zonal and local rank (fields and deposits) with the mapping of the real (mineral and geochemical) composition and other properties and structure of the ore bodies (and surrounding deposits) by establishing hydrodynamic mechanisms, lithodynamic conditions and tectonic modes of their formation.

The combining of these two areas of author's modeling provides the different scales, increasing resolution and predictive functions for final model, which we named: Digital structural-lithological model with geological-dynamic filling. The result may be considered as retrospective-static modeling.

Retrospective-static modeling consists of two elements. The first one reflects the dynamics of objects in time (in the reverse order - from a study of modern state to decors likely last). The second element (static) describes a stationary object structure now or simulated condition at short stages in the past, when the system variability can be neglected without significant error.

Both elements are interrelated: the identification of placer environments and paleo evolution based on its existing structure, the reconstruction of geological and dynamic processes allows to give a predictive assessment of metal-bearing placer.

### Logic-Information Modeling

The creation of forecasting-search models of placer deposits and construction of decision rules to estimate the area, promising to detecting placer, are priorities in deposit predicting.

The evaluation of placers is carried out consistently by solution of following tasks:

1. An estimation of prospects of area;
2. In case of revealing of a prospecting area the estimation of productivity of perspective area is spent.

We have applied logic-information analysis ([3], [4]): a special algorithm of the pattern recognition method, based on the study of variation object range and the similarity concept. The essence of this method is to outline the informative attributes to distinguish different groups of data sets and estimate their significance for evaluation of this difference and similarity. The identification of the informative attributes is based on the principle of the common features of sites, belonging to the same class.

To distinguish the attributes that are informative for description of class  $A_k$  and separate it from other classes, we have used the functions, based on: probability that attribute  $j$  presents at the sites of class  $A_k$  and does not present at the sites of other classes; probability that attribute  $j$  does not present at the sites of class  $A_k$  and presents at the sites of other classes. They are used for construction of the decision rule for the site identification: the site belongs to that class which has the maximum value of the function. As a result, we have a relationship of coefficients for an examined site, which characterizes the similarity degree of this site with other classes.

The mathematical processing of data has allowed us to compile logic-information models (the set of attributes, informative for indicated tasks, with weights of their importance for solving of the problem). For example, solving the first task for gold alluvial placers, we have received the model "prospecting area" as the set of 14 attributes from metaattributes: basis, ore, morphostruture, substrat, structure of valleys - with weights in diapason from 0.046 to 0.58.

The rules for making decision have allowed to create expert system and determine correctly all placer deposits from database. Technology of hybrid expert systems ([4], [5]) is the best for development of expert systems based on digital models for target prediction and evaluation of placer objects, because it permits using different

kinds of knowledge about the object of study in various forms, allowing their automatically applying during operation of the expert system.

### Conclusion

Obtained results show that the Retrospective-static methodology (Digital structural-lythological model with geological-dynamic filling) represents modern, efficient technology of information management of all R&D stages, which aimed at the development of placer titanium-zirconium, cassiterite, gold and rare metals ores deposits. Further modeling perspectives comprise on the one hand the methodology introducing into the investment projects implementation, and on the other - to further its development for a wide range of genetic types of deposits and its transformation into a permanently functioning models and expert systems which provide a solution of the complex issues related to deposits operation and environmentally reasonable minings closure with remediation of disturbed territories.

### ACKNOWLEDGEMENTS

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## COMPILATION AND DISSEMINATION OF A DIGITAL DEEP SUBSURFACE MODEL OF THE NETHERLANDS.

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**KEY WORDS:** *Digital workflow, deep subsurface, 3D-model, on- and offshore, regional model, petroleum geology, seismic interpretation, stratigraphy, subsurface viewer.*

### INTRODUCTION

Since 1985, the Geological Survey of the Netherlands (TNO-GDN) has carried out several major mapping projects. The results have been integrated to compile a consistent, regional-scale petroleum geological framework for the deep subsurface of the Netherlands, both on- and offshore. The geological products, such as maps, grids, stratigraphic charts, specialised studies and more recently the 3D-model 'Digital Geological Model-deep (DGM-deep)' are publicly available. With the latest publication of DGM-deep increasing effort is put into more sophisticated ways of dissemination.

Initially the onshore mapping of the deep subsurface of the Netherlands was executed and published on paper (Geological atlas, 2004). The offshore domain has been studied between 2004 and 2010 (Kombrink et al., 2012) and since 2010 the onshore area is in the process of revision. The mapping products are based on publicly free subsurface data mainly acquired by the oil industry. In 2003 a new mining law was issued and a large quantity of well- and 3D seismic data became publicly available. In the last decade, by using an increasing amount of these publicly free subsurface data, the modeling approach has led to a much more detailed set of stratigraphic well tops, time and depth grids. The modelling approach furthermore developed into a fully digital workflow resulting in the current 3D DGM-deep (fig.2).

### MODEL DETAILS DGM-DEEP

DGM-deep is a regional subsurface layer model covering the on- and offshore of the Netherlands. Twelve geological horizons, ranging from Carboniferous to Neogene in age, are the constituents of this compiled grid model. The model is based on interpretations of 2D and 3D seismic survey data (fig.1), combined with a variety of well data, i.e. sediment cores, gamma ray-, sonic- and occasionally neutron logs. The

well data is supported by biostratigraphical, petro-physical and geochemical analysis. All publicly free 3D-surveys and 1305 wells have been used to stratigraphically constrain the modelling process. The interpreted seismic horizons are the bases of lithostratigraphic units which are described in the Stratigraphic Nomenclature of the Netherlands (Van Adrichem-Boogaert & Kouwe, 1993).

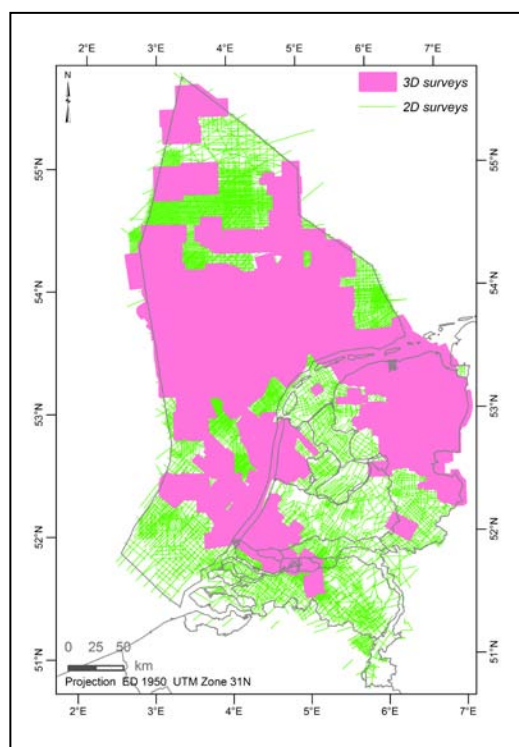


Figure 1 – 2D and 3D seismic coverage of the area.

The general approach and workflow corresponds to that of the hydrocarbon E&P industry. It includes the interpretation of horizons from 3D and 2D seismic data in the time domain (two way travel time). Horizons are merged into one geometrically coherent stacked grid model in the time domain. They are subsequently converted to depth using a layer cake velocity model built from well log and checkshot data (cf. Van Dalfsen et. al. 2006). Interpreted well markers support the identification of stratigraphic units in the seismic data and they are used for well-tie in the depth domain. Misties of each horizon grid with the well

marker depths are analyzed and kriged over the model area. Merging the mistie-grids and time-depth converted grids result in a stacked model that acknowledges the well data. Finally an attempt has been made to assess model

uncertainty through stochastic simulations of time-, velocity- and depth-grids. Resulting standard deviation grids combined with the mistie-grids provide insight in the error bandwidth associated with the model.

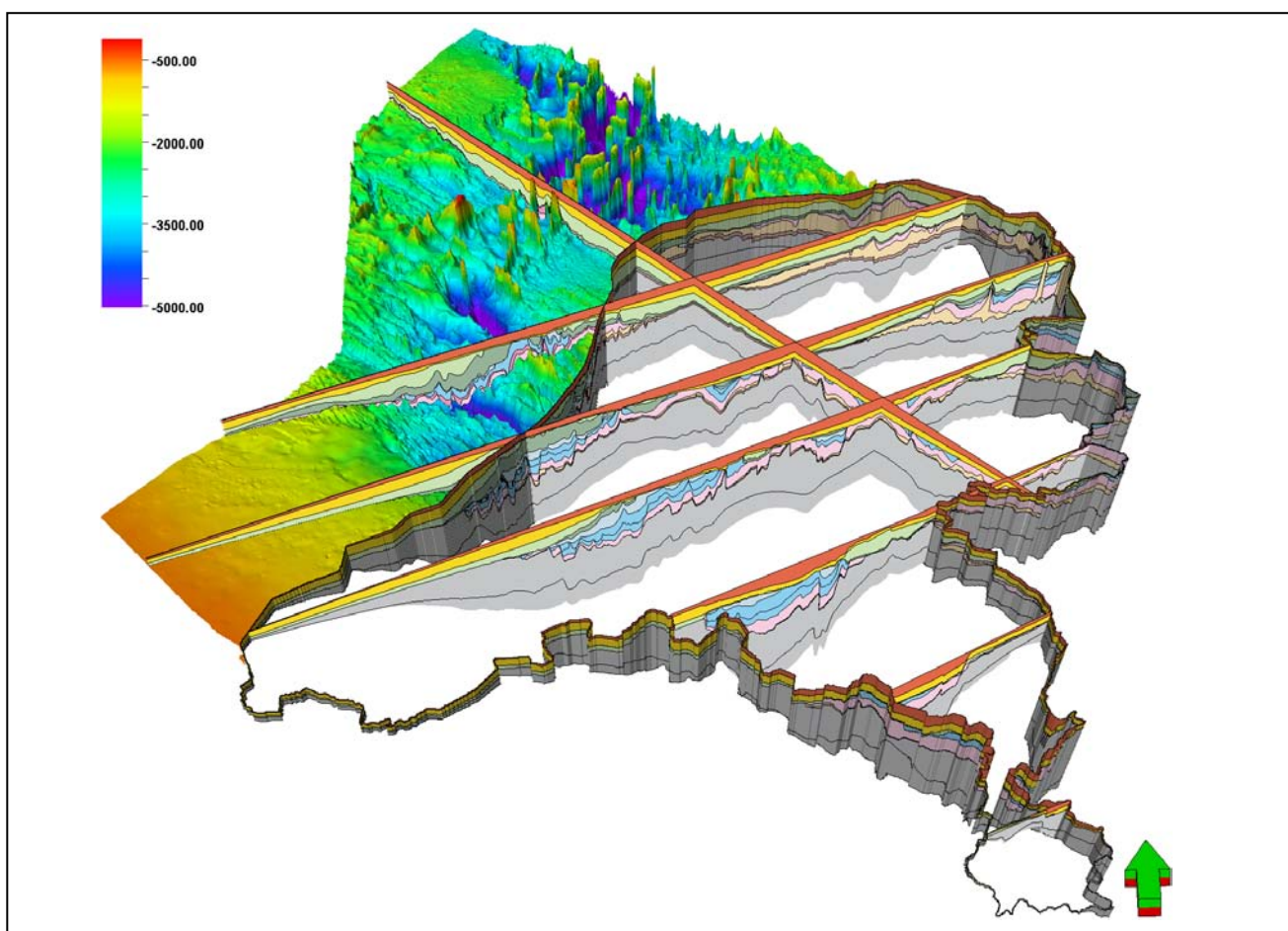


Figure 2 – Fence diagram of DGM-deep. In the offshore area the top Paleozoic horizon is shown.

## DISSEMINATION OF THE MODEL

Previous versions of the DGM-deep models and related data can be retrieved through the Dutch oil and Gas Portal (<http://www.nlog.nl>). In 2015, a new version of the onshore model has been released that can also be examined in a sub-surface viewer via the portal DINO-loket (<https://www.dinoloket.nl>). The viewer enables selection of random x-sections through the model, generation of vertical cores at random locations, and selection of maps and well stratigraphy. Furthermore a selection can be made for downloading various grid types and formats (Arcgis and Zmap) and a 3D-viewer.

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## 3D PALEOSEISMOLOGY TO OBTAIN NET SLIP-RATES FOR LATERAL STRIKE SLIP FAULTS WITH A REVERSE COMPONENT

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**KEY WORDS:** 3D paleoseismology, strike-slip fault, net slip-rate, Alhama de Murcia fault

### INTRODUCTION

The seismic potential of an active fault scales with its slip rate. While the net slip rate can be usually obtained with 2D studies in faults with net strike slip or dip slip kinematics, a 3D analysis is shown to be necessary for faults with combined lateral and dip slip vectors, otherwise the analysis would rest uncompleted. Alhama de Murcia fault (AMF; SE Iberian Peninsula; Fig. 1) is a left-lateral strike slip-fault with a reverse minor component that has been proven to be seismogenic. Only studies focusing in one component have been held in this fault to date. Masana et al. (2004) suggested a vertical slip-rate of 0.04-0.35 mm/yr, and Martínez-Díaz et al. (2003) obtained a lateral slip-rate of 0.21 mm/yr, both studies showing large uncertainties. Our study aims to obtain the vertical, lateral and net slip-rates using a 3D trenching analysis (Fig. 1).

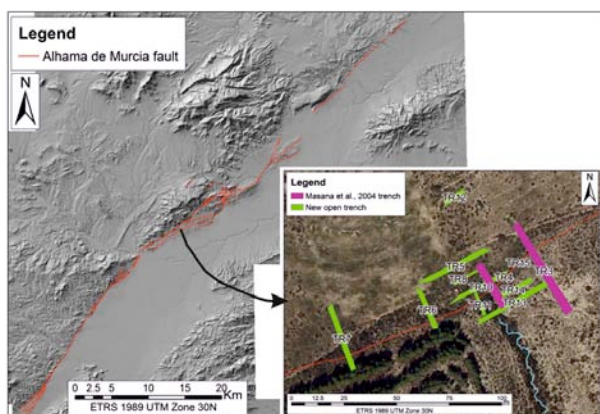


Figure 1. Alhama de Murcia fault and the position of the trenches.

### METHODOLOGY

We integrated a paleoseismic analysis with a morphotectonic analysis of offset linear features (mostly channels) to obtain the net slip-rate values. In a simplified way, a channel is a linear feature, but at a more detailed scale, its base is a surface composed by infinite lines. Each one of these lines is named piercing line (Fig. 2A) and has its equivalent at the opposite side of the fault. The offset between the piercing points of equivalents piercing lines is used to calculate the slip-rate. In the trenches, we selected reference points in the outcropping channels that correspond to the intersection of these piercing lines with the trench wall (Fig. 2A). For at least two trenches on both sides of the fault (four walls), we identified the equivalent reference points. The position of the reference points was recorded in the field with a GPS (Leica Zeno 5). The best 3D fit line (piercing line in Fig. 2A), the projection of this line into the fault plane (piercing point in Fig. 2A) and their associated errors were calculated with new Matlab scripts. We applied the probability density calculation functions proposed by Zechar and Frankel (2009) to resolve the mean values for the displacements and for the slip-rates.

### RESULTS AND DISCUSSION

The study is located on a Late Pleistocene alluvial fan named "El Saltador". We identified a buried channel (in unit D) on both sides of the fault. Offset and slip-rate estimates for this linear feature are expressed by a mean of the piercing lines identified and calculated (and by median and  $2\sigma$  bounds).

The vertical mean offset for unit D is  $-1.36$  m ( $-1.35 \pm 0.11/-0.09$  m), the mean lateral offset is  $15.89$  m ( $15.49 \pm 2.59/-0.71$  m), and the mean net offset is  $15.95$  m ( $15.55 \pm 2.59/-0.71$  m). The vertical offset is the smaller one and is a negative value, indicating that the AMF at El Saltador is predominantly a strike slip fault with a small reverse component.

Dating of the units described in El Saltador site is in progress. A radiocarbon-dated charcoal sample taken from the underlying unit H yields a calibrated age of  $25,228-25,832$  a cal BP ( $2\sigma$  interval). As unit H is stratigraphically much lower

(Fig. 2B), unit D is younger than  $25,228-25,832$  a cal BP.

We obtained minimum slip-rates, as we used a maximum age for unit D. The mean minimum vertical value is not well-constrained, so we are not using it. The obtained mean minimum lateral slip-rate is  $0.62$  mm/yr ( $0.61 \pm 0.10/-0.03$  mm/yr), and the net slip-rate is  $0.62$  mm/yr ( $0.61 \pm 0.10/-0.03$  mm/yr). Even being a minimum, these values are larger than those suggested by previous authors. These values should be taken into account in the seismic hazard assessment in the area.

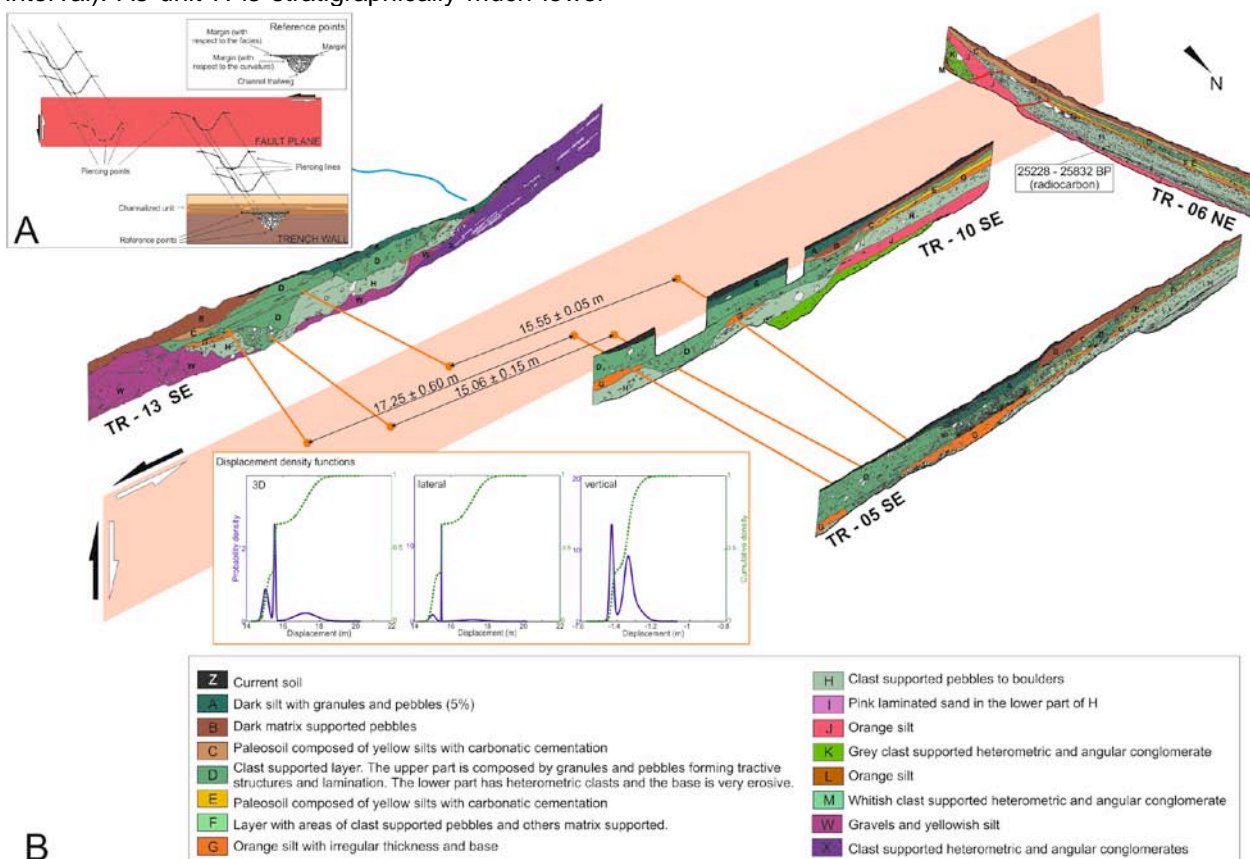


Figure 2. A: Diagram showing the methodology used to calculate buried paleochannel tendency in order to obtain piercing points in the fault plane. B: Three-dimensional model of the El Saltador trenches. Piercing lines, 3D offset measurements and  $^{14}\text{C}$  dating are shown.

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## Calculating CO<sub>2</sub> storage capacity in an unconformity trap formed at the backlimb of a fault-propagation fold: The Mar Cantabrico-E1 detritic reservoir (Cantabrian Margin, Spain)

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**KEY WORDS:** Cantabrian Margin, CO<sub>2</sub> storage, structural top contours, unconformity trap, fault-propagation fold

### INTRODUCTION

The Cantabrian margin of Spain contains three candidate sites for geologic CO<sub>2</sub> storage studied in the framework of the ALGECO2 project. Here we focus on the reservoir drilled by the MC-E1 borehole 11.5 km in front of the coast of San Vicente de la Barquera (Fig. 1). To characterize the storage geological structure, 29 multichannel seismic profiles from several geophysical surveys have been used. Seismic lines trend N-S and E-W with a total length about 440 km.

The MC-E1 borehole is located in the offshore extension of the Nansa Belt defined by Espina (1997) as an imbricate of south-directed fault-propagation folds that reactivate eroded variscan thrusts and Permian, Triassic and Lower Cretaceous extensional faults. The Nansa Belt forms a wedge on a major ramp in the middle crust, much like the ramp described by Pulgar *et al.* (1996) in a more external section. The frontal thrust of the wedge is the Cabuérniga fault, formed in a triple junction (in the sense of Narr & Suppe, 1994) as the ramp intersects the large Permo-Triassic Cabuérniga fault. The trailing thrust of the wedge is the Tresgrandas thrust (Fig. 1) which contains the unconformity trap at their rotated hangingwall.

### GEOLOGIC CROSS-SECTION

A detailed cross-section of the Tresgrandas fault-propagation fold has been constructed on the basis of surface, seismic and well data (Fig. 2). The fold has a short footwall syncline with a sliced upturned limb. Their anticlinal crest exposes the variscan basement at the level of the basement-cover contact (D1 angular unconformity, which approaches 90° here). The hangingwall of the thrust is a large block inclined to the north and folded as a gentle syncline. This syncline preserves a denudation complex (Oyambre Fm) developed over the D2 unconformity. The age of

the Oyambre Fm extends from the Late Eocene (Priabonian) to the Oligocene.

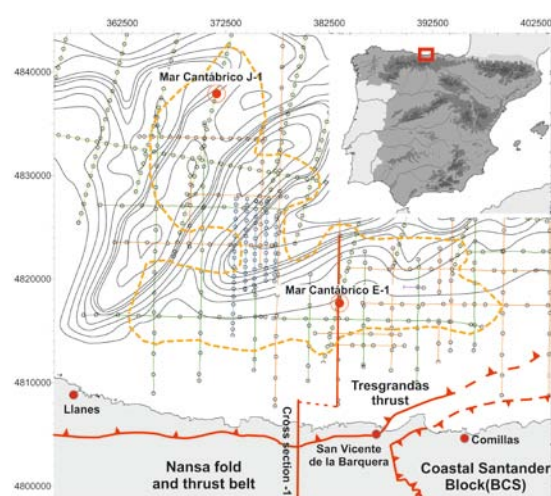


Figure 1 –Map of the Cantabrian Margin around the MC-E1 oil well with locations of the seismic lines and the line of cross-section in Fig. 2

The Sub-Miocene D3 unconformity truncates the previously folded beds and is therefore interpreted as a post-contractual feature. Later deposits filling the basin relief correspond to prograding claystones.

### RESERVOIR DEFINITION AND CAPACITY

The MC-E1 borehole with a total measured depth of 2246.8 m penetrates a reservoir in the Oyambre Fm between the D3 and D2 unconformities. This reservoir is heterogeneous with two non-communicating conglomerate layers: the Unit 2 (109 m thick) and the Unit 4 (640 m thick), separated by marls and claystones. Their average effective porosity calculated from Gamma Ray and Bulk Density logs analysis is 6%.

The caprock consists of about 450 m of claystone providing an effective seal only for the conglomeratic Unit 2, while rocks of the Unit 4 remain exposed on the seafloor. Therefore, only



the Unit 2 is considered here as a sealed reservoir.

The structure contour map on the top of the Unit 2 (Fig. 2) reveals how the large E-W backlimb of the Tresgrandas thrust interfere in north direction with transverse and oblique folds.

The calculations of rock volumes and CO<sub>2</sub> storage capacity for the Unit 2 are shown in Table 1.

Rock volume (m <sup>3</sup> )	8667.920E+06
Porosity volume (m <sup>3</sup> )	938.720E+06
CO <sub>2</sub> storage capacity (tn)	704.040E+06
CO <sub>2</sub> efficient storage capacity (tn)	211.212E+06

Table 1 – CO<sub>2</sub> Storage capacities in the conglomeratic reservoir of Unit 2. The efficiency factor used here is the 30% of the CO<sub>2</sub> storage capacity.

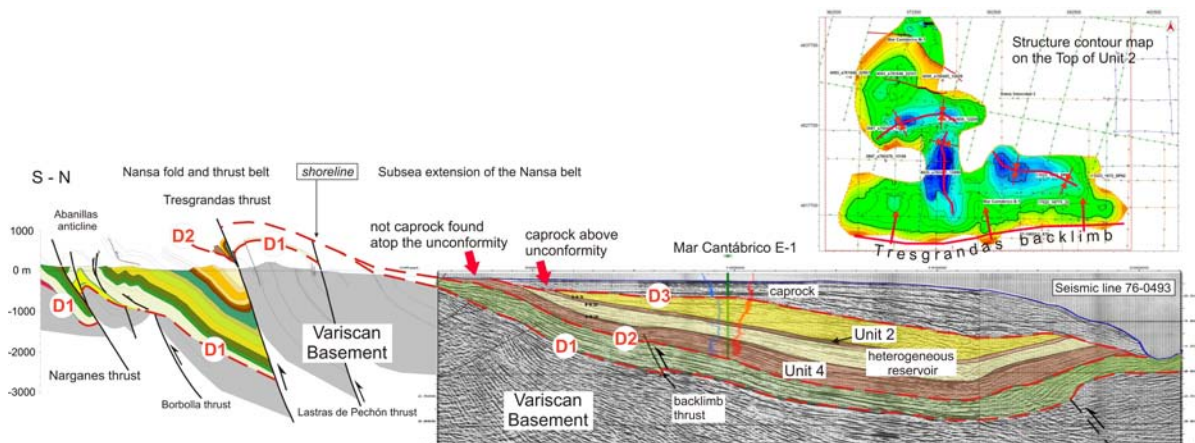


Figure 2 – Cross-section-1 and seismic line 76-0493 with the interpretation of the structure of the MC-E1 reservoir and trap. D1 Top-variscan unconformity; D2 Syn-contractional Priabonian unconformity; D3. Post-contractional Sub-Miocene unconformity. The inset at the top right is the contour map on the top of the conglomerate reservoir rock of Unit 2.

## CONCLUSIONS

The MC-E1 borehole drilled a heterogeneous reservoir in the Oyambre Fm at the backlimb limb of the Tresgrandas fault-propagation fold. The reservoir is formed by two non-communicating conglomerate layers separated by marls and claystones. Only the thinnest (109 m) of these units is covered and sealed by the Miocene caprock in an unconformity trap. The available data indicates that the MC-E1 well is a suitable candidate for geologic CO<sub>2</sub> storage with an efficient capacity of 211.212E+06tons.

## ACKNOWLEDGEMENTS

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## Preparation of Gocad-Skua models for numerical simulations

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KEY WORDS: meshing, volume discretization.

3D models describe the geometry and structure of geological bodies mainly by boundary surfaces between geological units. The 3D models are produced in special geomodeling software adapted to the peculiarities of geological data like scarcity and uncertainty. Software that is widely used as geomodeler is Paradigm Gocad-Skua, which produces independent surfaces with an unconformable triangulation at the surface contacts.

One aim of our work is to utilize Gocad-Skua models for numerical simulations that may aid in underground monitoring, strength prediction and mineral exploration. The physical relations are usually described by partial differential equations that are solved approximately by methods like the finite difference method (FDM), the finite element method (FEM) and the distinct element method (DEM). These methods require different kinds of discretization of the modeling domain that have to be produced from the geological surfaces modelled with Gocad-Skua. Since every method has advantages and disadvantages, it can be used for special practical problems. Therefore, we wanted to apply three simulation methods to one 3D model and to check how the model has to be prepared. We chose three methods with different kinds of volume discretization:

- The DEM can describe the motion of discrete body elements (blocks or spheres) of materials. It is well suitable for the description of brittle material behavior. If two elements have a contact, a contact force arises. This contact force is determined by a specified contact model. The element motion is determined by the resultant body force and described by Newton's Law of motion.
- The FDM solves partial differential equations by replacing derivatives by simple differences. This results in algebraic equations describing the unknown variable on discrete points in the modeling domain. The method is easily to implement on regular grids with constant step width (differences). That's why models that should be passed to FD simulation have to be discretized by regular hexahedral grids.
- The FEM replaces partial differential equations by a set of piecewise continuous basis functions which are expressed within the finite elements. The basis functions are used to solve the resulting equation system numerically. Initial and boundary conditions are included. The result is an approximation for the solution of the original partial differential equation system. The accuracy of the output depends on the

element size. The FEM allows to model complex geometries using an unstructured tetrahedral discretization.

If a model that was produced in Gocad-Skua shall be passed to one of the simulation methods mentioned above, the first step consists of combining loose surfaces to a boundary representation. A watertight boundary representation is achieved when the volume of the body is completely confined and partitioned by surfaces without holes and overlaps. If the boundary representation is not watertight, the volume discretization fails.

Different methods can be used to produce the boundary representation from a Gocad model, such as the Tweedle plugin (Pellerin et al. 2011) or the CompGeom plugin (Zehner et al. 2011). Both workflows pass the Gocad model to an external meshing software like Graphite (Alice, 2015) or Gmsh (Geuzaine and Remacle, 2009).

The modeling domain can be discretized in Gocad-Skua using the boundary representation, if a regular hexahedral grid is needed, such as for a FD simulation. In this case, a Voxet object can be generated for the modeling domain, and this modeling domain can be partitioned into regions confined by the boundary surfaces. Each region gets an ID number indicating the geo-object. The Voxet can be exported as txt-file. If an unstructured tetrahedral mesh or a discrete particle model is needed, the volume discretization has to be performed outside of Gocad-Skua. The boundary representation can be passed as smesh-file to TETGen (Si, 2011) in order to produce an unstructured tetrahedral mesh. If the model is partitioned by internal surfaces, TetGen can recognize this, and each tetrahedron is assigned a number indicating the partition it belongs to. This number can be later used for setting material parameters. The TetGen output can be used as input for the simulation software or be imported back into Gocad-Skua for quality control and further processing, such as interpolation of attributes onto the elements. One possibility to use the DEM is provided by the software PFC<sup>3D</sup> by ITASCA. This software uses balls as discrete elements. It can import stl files in order to describe complex geometries. This geometry objects can represent the boundaries of the volume partitions or of the whole model. If necessary they can be transformed into walls that represent model or region boundaries. Each volume partition can be filled with balls that comprise one material with

specific model parameters such as stiffness and bond strength. If used, the internal walls have to be deleted for allowing an interaction of the different materials. This model can be used for the numerical simulation.

We suggest saving 3D underground models as watertight continuous boundary representations, because this is needed for all kinds of volume discretization. If the model is available in a watertight boundary representation, it can be easily passed to different simulation software and 3D models can be used for multiple purposes like groundwater simulation, stress field simulation,

mineral potential modeling or for the simulation of geophysical monitoring methods.

#### ACKNOWLEDGEMENTS

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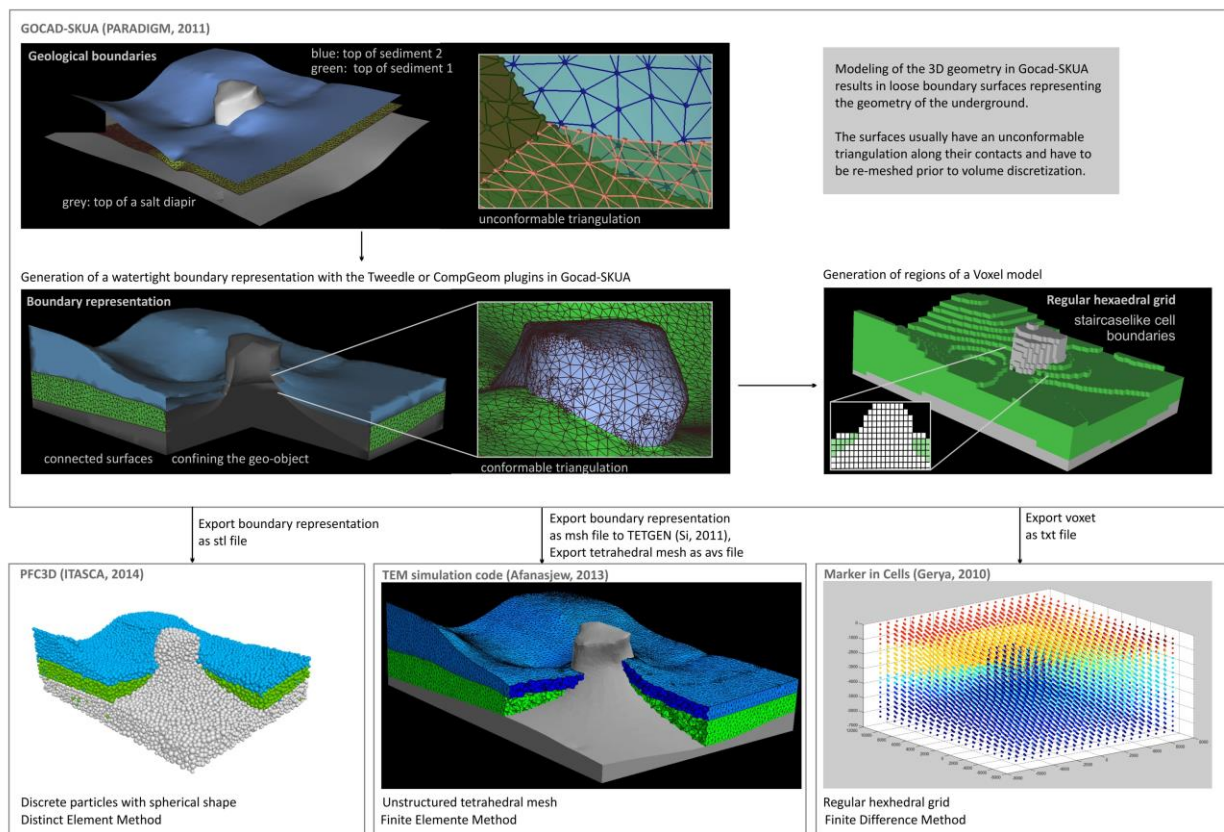


Figure 1 – Preparation of one 3D model produced in Gocad-SKUA for the numerical simulation with 3 different methods. A watertight boundar representation is needed for all simulation methods.

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## Updating the 3D geological model of Catalunya v. 1.0: the northern sector of the Neogene Empordà Basin (NE Catalunya)

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**KEY WORDS:** 3D geological model, structural analysis, data management.

### INTRODUCTION

The geological community in the last years has been engaged in developing new technologies and workflows for acquiring, processing, analysing and visualizing geological and geophysical data. This is closely linked to advances occurred both in computers (both hardware and software) and the availability of digital data, which have opened a new era with increasing possibilities to work with huge amount of data and different formats. This advances allow us to integrate more hard data with geological knowledge or constraints derived from the analysis of raw data. To do that, a valid 3D approximation and workflow must be used to minimize errors and to obtain valid 3D geological models.

Being aware of this, the Geomodels Research Institute and the Geological Survey of Catalonia (ICGC), worked to obtain (in 2013) a first version of the 3-D geological model of Catalunya at 1:250.000 in order to take an important step in the geology disclosure as well as the type and quality of the geological product generated.

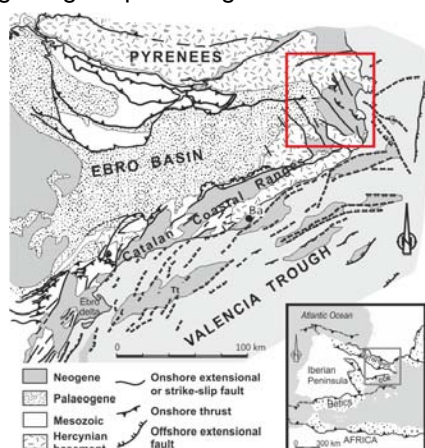


Figure 1 – Situation of the updated area (red square), NE part of Catalonia.

Taking this 1:250.000 preliminary 3D geological model as a baseline model, an updated version is now presented. In this new version, the northern sector of the Neogene Empordà Basin (NE Catalonia, red square on Figure 1) has been

updated, taking into account data from 1:25.000 geological maps and new available data.

### 3-D RECONSTRUCTION

The workflow developed and followed for the 3-D deterministic reconstruction is based on the explicit reconstruction methodology (Groshong, 2006, Carrera et al., 2009) that implies: establishing 3-D geometric relationships between initial hard data; the use of initial data in its initial position in a 3-D space; avoid intermediate interpretations in 2-D cross-sections; and incorporating geological criteria in the data management.

Although the explicit reconstruction is more laborious than implicit approximations (Caumon et al., 2007, 2009; Calcagno et al., 2008), for our purposes, it provides a greater control and understanding over each reconstruction step and on the reconstruction of complex structures (multivalued, discontinuous, with nonuniform data distribution, etc).

### THE CATALUNYA 3-D GEOLOGICAL MODEL. METHODOLOGY

Taking into account this 3-D reconstruction assumptions, the methodology used to generate the 3-D geological model of Catalonia can be summarized as follows:

- Adequacy of information. Collecting information from different sources involves different data formats. All this data must be transformed for its use in a common 3-D graphic environment.
- Database update. At the same time, the previous database is updated including the new available data.
- Adding information in a common 3-D graphic environment. Collect and visualize all available information in a single software (Gocad - Paradigm®).
- 3-D reconstruction. Deterministic geological surface 3-D reconstruction honoring all available data and incorporating geological constrains derived from structural analysis (cilindricity, dip domains, plunge lines, etc.)
- Adequacy of the 3-D geological model to a common format as universal as possible.

The hard data used to update the 3-D geological model can be grouped into:

**Surface data:** digital geological maps of the target area at 1:25.000 in raster and vectorial format; Digital terrain model of 100 x 100 m.

**Subsurface data:** well data and seismic data (in SEG-Y).

**Derived data:** combination of surface and subsurface data to obtain new geological data like cross-sections or contour maps (isopachs or isobaths).

Considering this new data, the final model include the updated boundary surfaces of geological units, as well as, the main faults that configure the geological structure in the studied area (figure 2). The initial surfaces have been derived from the previous 3D model and modified accordingly to the new available data. In addition, new surfaces have been reconstructed in order to represent new units (or faults) with a geological significance in the studied area (e.g., Messinian unconformity or the Neogene bottom).

## DISCUSSION AND CONCLUSIONS

Summarizing, the use of the described methodology allows to integrate a variety of information with different file format in a common graphic environment. In turn, it provides fast and effective acces to information and it is valuable to solve data base and geological inconsistencies.

New computer technologies combined with a valid 3-D geological reconstruction methodology, can address the disclosure and understanding geology in a more efficient way.

The construction of the 3D model has revealed as crucial for the geological understanding of the area provided the superposition of the Paleogene Pyrenean structures and the Neogene extensional system and the obliquity between both sets of structures. In addition, the Pyrenean structures show significant along strike variations and a general plunge towards the east at the eastern termination of the Pyrenean onshore units. These features difficult the construction of geological cross-sections and the understanding of the main geological features based on the available maps. Moreover, the geology of the area has a significant impact for the society provided the seismic hazard

## ACKNOWLEDGEMENTS

The support of the project FBG308009 is acknowledged. Move (Midland Valley) and Gocad (Paradigm) are used to generate the 3-D model.

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associated with the Neogene extensional faults and the extensive human use of the geological resources in the Neogene basins.

Regarding to the geological interpretation, the new model allows to show more clearly the relationship and the geometry of the geological features that define and configure the internal structure of the Pyrenees and the younger extensional Neogene fault system. More specifically, the eastern termination of the Bac-Grillera/Serra-Cavallera thrust sheet (that was not solved in the previous version); the South Pyrenean Basal thrust and the related overlaying thrust sheets; as well as, the relationship between the Figueres-Montgrí thrust sheet and the Sant Climent Sescebes and Garriguella Fault.

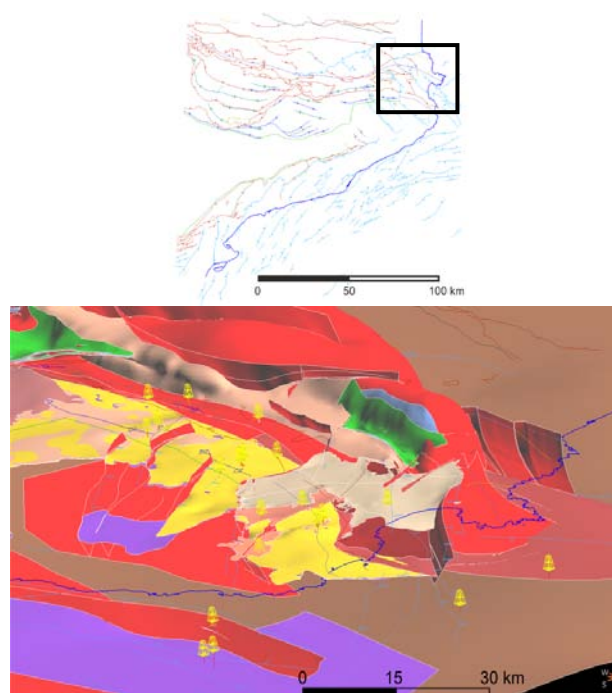


Figure 2 – Situation, structural map and the updated NE part of the 3-D model of Catalonia.

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## NEW GEOLOGICAL MODELS FROM THE BRITISH GEOLOGICAL SURVEY

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**KEYWORDS:** 3D geological modelling, decision support systems, web-based delivery, British Geological Survey.

### INTRODUCTION

Over the last decade many Geological Survey Organisations worldwide have begun to communicate their geological understanding of the subsurface through 3D geological models, and the traditional printed geological map has been increasingly phased out. This shift of emphasis has been made possible by modern computers, geological modelling software and delivery tools. The role of the geologist has however remained essentially the same, to gather all the relevant evidence (maps, boreholes, geophysics etc) and to come up with an interpretation of the geology.

Today BGS uses a range of modelling techniques varying from interpretative, deterministic to stochastic, depending on the geological situation and how much data is available. The main modelling software includes GSI3D, GOCAD-SKUA used for structural geological modelling, Petrel which is mainly used for reservoir modelling and also 2D Move for section restoration and fault dynamics.

Clients for models are many and varied and have included the Environment Agency (EA), Nuclear Decommissioning Authority (NDA), the Department for Energy and Climate Change (DECC), together with the Water, Utility, Transport and Engineering sectors. Models have also been built for educational and research purposes.

Two recently released outputs are the GB3D onshore bedrock model and the London and Thames Valley model.

### THE GB3D BEDROCK MODEL

Over the last five years as part of its National Geological Model programme combined with external funding, BGS has constructed a national resolution fence diagram model of the onshore bedrock geology of Great Britain (Figure 1).

The model covers England, Scotland (except the Shetland Isles) Wales and the Isle of Man and was built with contributions from 17 regional specialists supported by a team of data managers and developers. The model broadly adopts the colour schema and geological classification of the

BGS 1: 625000 scale bedrock geology maps with some simplification, faults are indicated by offsets in the geology. Constructed using the GSI3D methodology (Kessler et al 2009), the sections are tied to over 300 important deep boreholes. The model also takes account of existing BGS onshore models of bedrock geology which are themselves underpinned by BGS's vast collections of boreholes, seismic lines and regional geophysical data. The cross-sections extend to depths up to 5 km, with a minimum depth of 1.5 km, together they comprise over 25,000 line kilometres of section. A similar model but at a deeper crustal scale covering parts of Ireland, Northern Ireland and Scotland was constructed in collaboration with the Irish and Northern Irish Geological Surveys and is described by Leslie et al (2013).

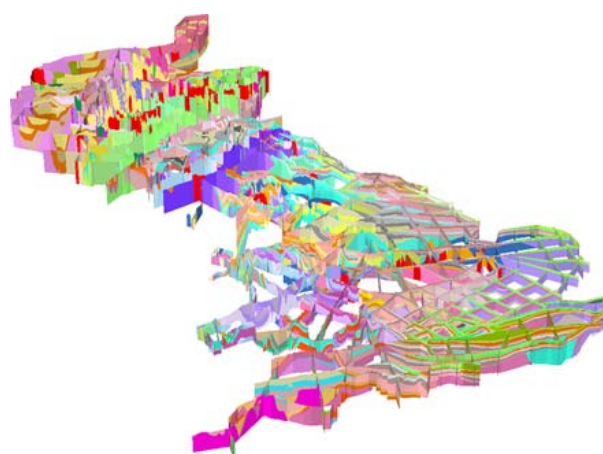


Figure 1 – The GB3D (v2012) fence diagram.

The latest version of the model is available for free download at <http://tinyurl.com/mlsz6j4>. The construction of the 2012 version of the model is described in detail by Mathers et al (2014).

In 2013 NDA decided that GB3D had the potential to act as a key source to inform the public about the geology of England and Wales, and subsequently to help facilitate screening for geological suitability for the location of a Geological Disposal Facility (GDF). Two phases of enhancement of the GB3D dataset were undertaken, the first involved the incorporation of 314 deep boreholes into the lines of cross-section and the second phase extended selected sections into the nearshore zone around England and Wales

GB3D has recently been used in the BGS iHydrogeology project to develop a risk screening tool for the UK's Department of Energy and Climate Change and the Environment Agency to consider the danger that could be posed by fracking of shale gas targets in terms of pollution of overlying aquifers <http://tinyurl.com/kfhnqr>.

### LONDON AND THE THAMES VALLEY MODEL

The London and Thames Valley model (Figure 2) is a full 3D volume model of the anthropogenic, superficial and bedrock geology down to a depth of a few hundred metres. The model is a subsurface extension of the 1: 50 000 scale digital geological map. It was built using a combination of GSI3D and GOCAD and covers 4800 km<sup>2</sup> along the London Basin encompassing an area 40 km in breadth stretching from Thatcham and Didcot in the west to Basildon and Tilbury in the east, the model is described in detail by Burke et al (2014). Similar models also exist for parts of southern East Anglia covering Ipswich, Sudbury, Colchester and Chelmsford, Manchester and Merseyside, Humberside and the Clyde Basin in Scotland. The model takes into account several thousand boreholes including most of those that exceed 100m in depth. It is suitable for use at a regional-district scale and can also act as a framework within which more detailed site or linear route models can be constructed. Examples include models built for the new Crossrail Farringdon tube station in central London and along the proposed HS2 route from Euston northwestwards towards Birmingham.

No anthropogenic deposits and shallow superficial such as Head and Clay with Flint are depicted in the model as 2D coverages draping the surface because modelling the 3D extent of these discontinuous deposits is very labour intensive.

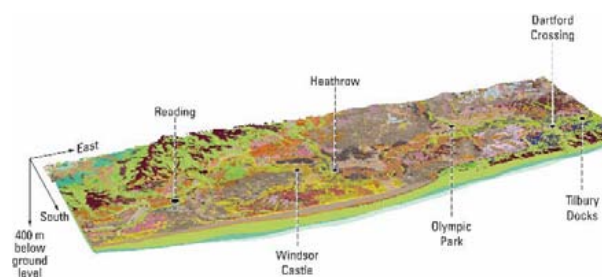


Figure 2 – The London and Thames Valley model viewed from the southwest, the pale green is the Chalk Group, mid-brown is London Clay, this view extends to the base of the Cretaceous strata.

### THE DELIVERY AND USE OF GEOLOGICAL MODELS

Geological models only make impact if they are delivered to users in an understandable form and

through an easy-to-use system, a point made well by Turner (2006).

The BGS and other organisations have been on a long journey to find suitable routes for publishing and delivering the results of modelling (see Kessler 2005) and recent years have seen real progress to the efficient delivery of models to clients, a summary of solutions across the EU has been published in a report by Kessler and Dearden (2014). A clear emerging trend is the increasing use of the Internet to disseminate models, the BGS' Groundhog web viewer (<http://www.bgs.ac.uk/services/3Dgeology/virtualBoreholeViewer.html>) is now deployed for the London and Thames Valley geological model as well as a series of free sample models, Figure 3 shows an output from the viewer.

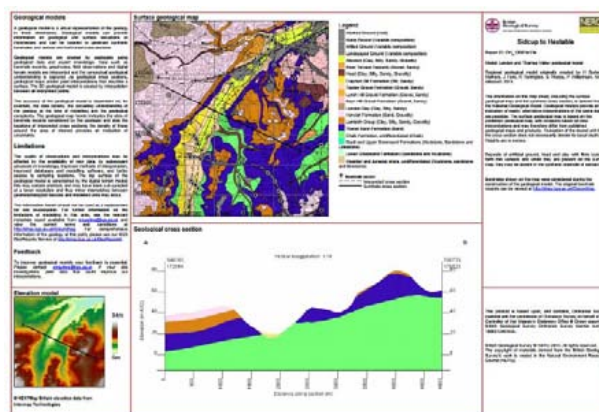


Figure 3 – synthetic cross-section report generated from the BGS Groundhog web-based model viewer

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# TOWARD OPEN DATA FOR BOREHOLE DATABASE AND 3D GEOLOGICAL MODELLING FOR SEISMIC HAZARD ASSESSMENT IN THE COASTAL PLAIN ADJACENT TO THE TOKYO BAY, JAPAN

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**KEY WORDS:** borehole data, 3D geologic model, seismic hazard, surface model.

such borehole data would be open data, over dozens of times of borehole data are available.

## INTRODUCTION

Borehole data obtained from geological and geotechnical investigation are indispensable in the urban area in Japan, not only for geotechnical information of city planning and building construction, but also for 3D geologic modelling for the seismic hazard assessment and groundwater hydrology. In Japan, Ministry of Land, Infrastructure and Transport (MLIT), prefectural and municipal governments, academic or geotechnical associations such as the Japanese Geotechnical Society and Japan Geotechnical Consultants Association have to spend much effort on accumulation of borehole data. In Japan, major borehole data are obtained by a standard penetration test that shows the ground's hardness/softness by *N*-value, the soil column and geologic stratum and the groundwater level and so on. The penetrations are usually accomplished up to the depth of the load bearing layer, ranging in depth from several meters to 100 meters. The term "borehole data" is referring to as such borehole data as follows.

The study reviews the development of borehole database in Japan and demonstrates 3D geologic modelling for seismic hazard potential map in Japan (Fig.1).

## TOWARD OPEN DATA

More than 200 thousands of borehole data obtained in public construction are open in public on the web sites of MLIT-"kunjiban", NIED-"Geo-Station", local governments and some academic associations. Recently, Science Council of Japan has offered the development of laws and rules toward open data of subsurface geological and ground information, which stress on borehole data of private company and persons. Few municipal governments have opened such borehole data. If

## FORMAT AND TOOLS

Digital data format of borehole data have been offered and revised by MLIT since 1981. The digital format (XML) of borehole data are called "exchangeable boring data format" (MLIT, 2008). There are some application softwares based on the format, which have a series of necessary functions of borehole logs for 3D modelling such as digitizing, quality control, database, viewer, and analysis. We have developed and opened in public these tools on the web in cooperation with Geological Survey of Japan, AIST.

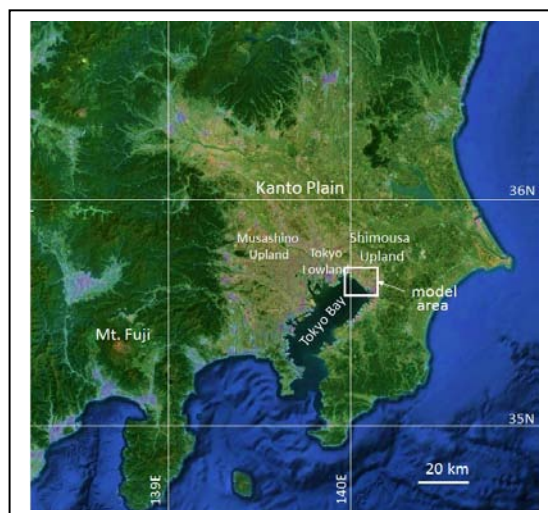


Figure 1 – Index map of the Kanto Plain, Japan. A square indicates the model area. (from Google map).

## 3D GEOLOGIC MODELLING

Borehole data are indispensable to construct 3D ground geological model in the urban area.



Most ground geologic models build on purpose of geoenvironment and geohazard are a square mesh-division type of model. In the mesh model, the model area is subdivided into meshes (ranging from 50 to 500m length), and representative borehole data are selected for each mesh based on location and topographic features. The area with shortage of borehole data is commonly made up for by spatial interpolation. In the case, the enhanced geologic understanding should be necessary. The useful method reflecting the geological understanding is to construct the surface model of the erosive geological boundary such as a sequence boundary and a transgressive ravinement surface. These surfaces commonly make a clear border of physical properties.

The following three surface models are important for controlling the spatial distribution of strata in the model area (Fig.2). The one is the basal surfaces of the fill and backfill soil (the Artificial soils), where most of liquefaction have occurred. The second is the basal surface model of the incised-valley fills during the latest Pleistocene

to Holocene time (the Recent strata) (Fig.2-3,4), which are characterized by very low Vs and low density which causes the high amplitude of earthquake. The third is both the basal and the ravinement surface models of the marine-bearing strata during the last interglacial stage (MIS5e) (the Kioroshi Formation). The ravinement surface (Fig.2-2) indicates appropriately the tilted structure of the Pleistocene Shimousa Group, and the basal surface suggests the index horizon of the seismic bedrock in earthquake engineering (Vs: more than 300m/s).

## ACKNOWLEDGEMENTS

We are grateful to Dr K. Asao of Chiba Pref. Govern., for sincere corporation and permission of borehole data.

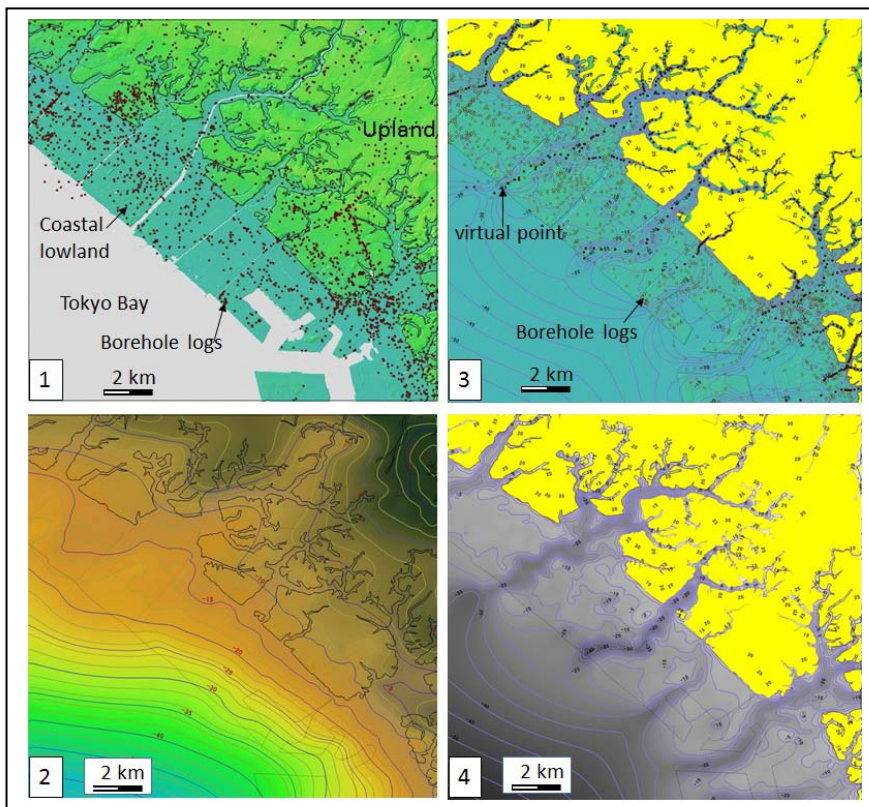


Figure 2 – Surface models of the coastal plain adjacent to the Tokyo Bay .

1) Topographic surface model made based on 5m dem from GSI, Japan, gradient tints diagram.

2) The surface model of the ravinement of the Kioroshi Formation, contour map,

3) The basal surface model of the Recent strata in the lowland area, contour map, small circles: borehole data and virtual points

4) the same of 3), gradient tints diagram.

Web site “Geo-Station” of National Research Institute for Earth Science and Disaster Prevention: [http://www.geo-stn.bosai.go.jp/jps\\_e/](http://www.geo-stn.bosai.go.jp/jps_e/)

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# MULTI-INSTITUTIONAL CO-OPERATIONS IN GEOSCIENCES AS A KEY FOR SUPPORTING BOTH SUSTAINABLE LAND-USE MANAGEMENT AND AN EFFICIENT DAILY BUSINESS OF A GEOLOGICAL SURVEY

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**KEY WORDS:** GIS, GOCAD, 3D-modelling, resources, web visualisation, expert information system

## INTRODUCTION

Geological surveys nowadays face several challenges they need to cope with. While the budgets are shrinking the tasks are increasing continuously. In addition hiring freezes and the related excess of age among staff lead to an increasing imbalance between available expert knowledge and the application/combination with state of the art methods such as Geo Information Systems (GIS), 3D/4D-modeling and web-based visualization of geoscientific content.

To meet this development, multi-institutional co-operations between the private sector, public authorities and universities seem to be promising. One example is a project that addresses the Quaternary sediments in the northern Upper Rhine Graben, Germany.

## MODELLING THE NORTHERN UPPER RHINE GRABEN

In co-operation with different institutions a GIS and GOCAD based 3D-model of the Quaternary has been developed for the northern Upper Rhine Graben which hosts the metropolitan region of Frankfurt/Rhine-Main. With 9,798 quality checked wells and information from hydrocarbon exploration insights regarding the depth level, the Base Quaternary was derived (only 144 wells reached the Base Quaternary), which required a modification of the up to now assumed geometry of the Quaternary sediment body. The Base Quaternary is affected tectonically, leading to a differentiation of the study area into at least five homogeneity regions. New knowledge about the geometry of the Quaternary has significant influence on current issues, particularly groundwater and related modelling.

The Quaternary body then has been parametrized with lithological information by

populating a stratigraphic grid (SGrid) that consists of about 15,000,000 voxels (Fig. 1). 3D-queries that are supported by this kind of modelling now enable a more profound decision making in the context of utilizing resources mentioned above.

## MAXIMISING THE REACH OF DATA AND RESULTS

To the successful execution of the project several institutions contributed, i.e. the Hessian Agency for the Environment and Geology (HLUG), Technische Universität Darmstadt, the Hessian Agency of Land Management and Geoinformation (HLBG), the land surveying office of the city of Darmstadt, as well as several companies that provided exploration data.

At the same time gained 3D-content often is available for a limited number of people only. Reasons for that e.g. can be limited knowledge in handling modelling software such as GOCAD or limited availability of software licenses. In addition decision making still is based on 2D-maps mainly.

Thus, and in many cases also due to the technical infrastructure related to expert information systems and data viewers, it often is required to transfer content from 3D back into 2D (Fig. 2). Therefore all data and results of the ongoing project are available for the HLUG and the co-operation partners on several platforms (GeODin, ArcGIS, GOCAD) as both vector- and raster data, providing content to every workplace within the survey through the expert information system and customers/externals through the data viewer, supporting daily decision making processes in order to address the increasing pressure related to the utilization of natural resources – e.g. soils, groundwater, raw materials, geothermal energy, building areas - and the resulting land use conflicts.

## FUTURE CHALLENGES

The project presented above still keeps many challenges. However, there are other regions which demand adequate investigations and

modelling, e.g. the Lower Main Plains (see Budde et al., this volume). Upcoming steps include the seamless union of models (even across borders of

three federal states) and an appropriate distribution, visualisation and maintenance/further development of content.

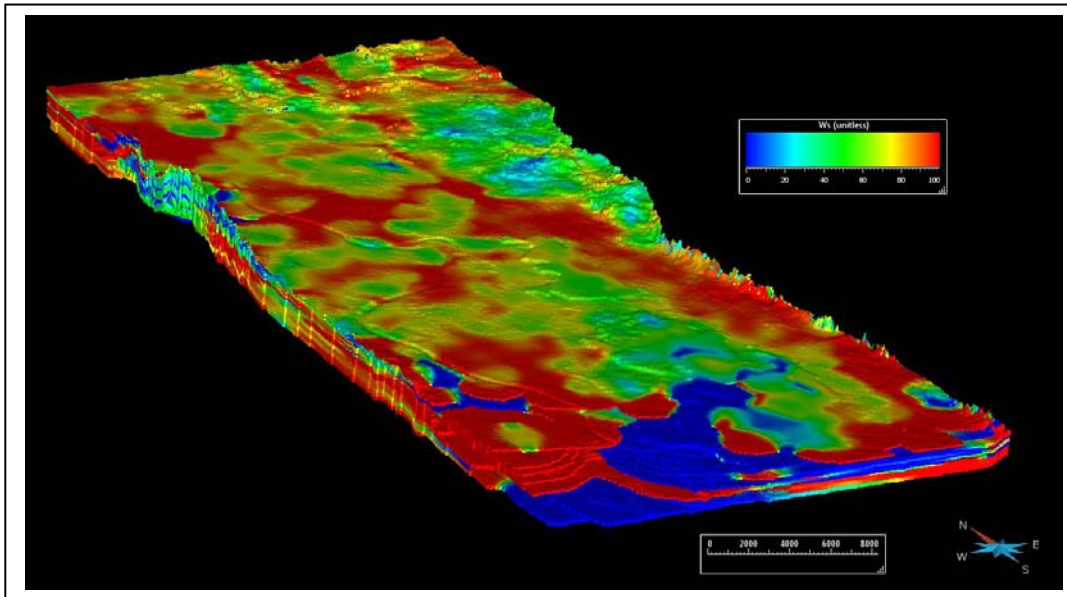


Figure 1: Based on the modeled geological strata so called SGrids can be generated in order to enable voxel-based parametrisation as well as interpolation of attributes throughout the SGrid. Displayed here is the appearance of grain sizes from clay (=red = cohesive layer) to gravel (= blue = non-cohesive layer). Altogether the presented SGrid consists of about 15,000,000 voxels. The area covers about 1,250 km<sup>2</sup> and reaches from Frankfurt in the North to Mannheim in the South.

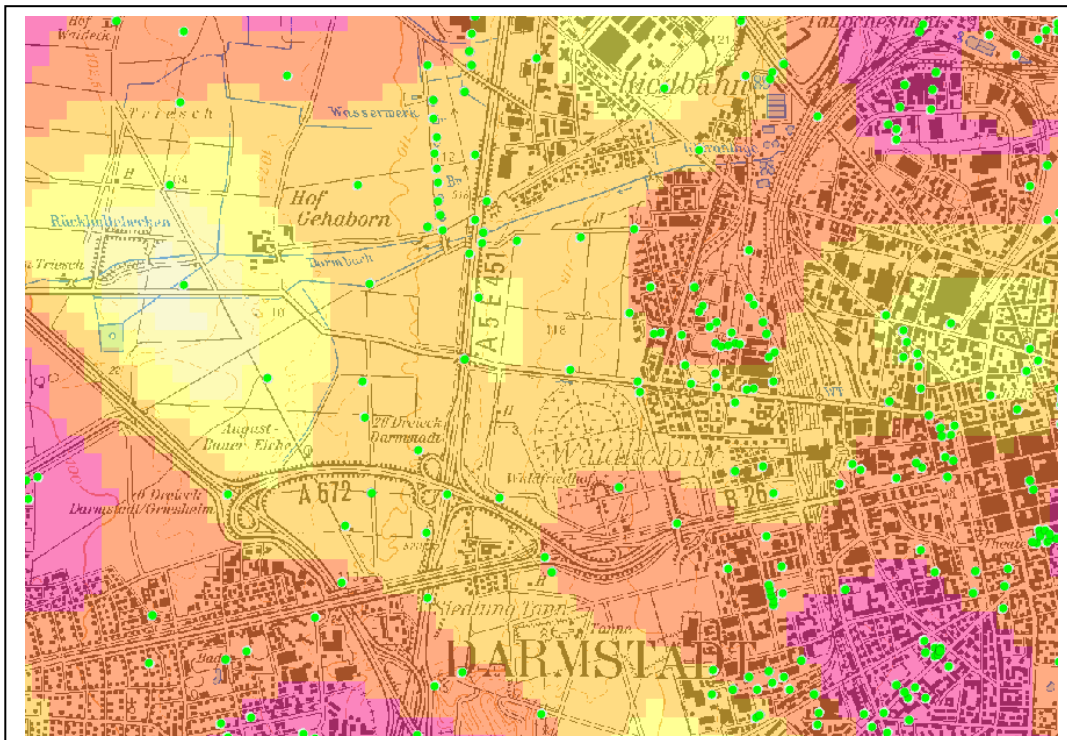


Figure 2: A layer in the expert information system which represents the calculated appearance of aquitards in the depth level 0 – 5 m for the area of Darmstadt. Purple indicates a high probability, bright yellow a low probability for the appearance of an aquitard. Green dots indicate drillings which have been the basis for interpolation.

## The 3D GeoloGiro

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**KEY WORDS:** Landscape, Geology, Maps, Sport, Dissemination; Italy.

### KNOWLEDGE AND DISSEMINATION

Modern technology provides society with increasingly sophisticated and efficient tools. New methodologies of analysis are developed to explore the themes and to broaden the range of research. The potential of 3D models is widely proven, and can be further developed; among the many features of 3D, the most representative is the display of significant images: the content of information and data inherent in the model, allows the users to configure systems evolution. In the field of earth sciences, thanks to these tools it is possible to follow the changes through time of the studied portions of the planet: from the investigable past to the present, from the present to the possible future changes. The pattern of the changes over time, in addition to bring an extraordinary value in almost all fields of scientific research, is a powerful vector of information. For example, the smartphone App realized by the British Geological Survey "iGeology 3D -The rocks around you", provides a fascinating and powerful tool for the whole society, useful to make understandable to the users the differences between science fiction and the invisible real - possible future. As in the philosophy of GIS, 3D tool is available at different levels of detail and complexity, so it can be effective for teaching as well as for spatial planning, or in the identification and management of resources, or risks. So, 3D modelling performs an effective function in the scientific communication, playing a key role in the activation of Prevention practices. It is of fundamental importance to link the modelling to reality, in order to convey the meaning of the model, not only in the spatial dimensions, but also through the diachronic one.

### PROJECTS @ I.S.P.R.A.

One of the most important cartographic projects in Italy, is the Geological Cartography project, coordinated by the Geological Survey of Italy – ISPRA. It provides for the realization of geological and geo-thematic sheets on a scale of 1:50,000: tools required for proper territorial planning and management and, in particular, for the prevention, reduction and mitigation of hydro-geological risk. The realization of 3d geological models is recently started, in an experimental way. Another project made within ISPRA is the Carta della Natura (law 394/91) that aims at assessing the state of the environment in the whole Italian territory. Each individual landscape, studied at different scales, shows distinctive elements; at a synthetic scale (e.g. 1:250.000 scale), physiography is the feature that best approximates the results of a landscape classification performed following an holistic approach. By integrating the geologic and physiographic components and the gathered data, it was possible to identify and describe the so called Landscape Physiographic Units.

### POPULARIZATION OF GEOLOGY THROUGH SPORTS: THE "GEOLOGIRO 3D" PROJECT

A recent proposal, developed and realized thanks to a cooperation between the ISPRA, the Council of Italian Geologists (CNG) and RaiSport, is the "GeoloGiro" . Its main goal is to attract the attention of the general public to the issue of describing the main features of the territory in terms of landscape, soil, and geology, taking as a "testimonial" the area crossed by the Giro stages. Therefore, we have prepared for each stage a 3D representation of the land, with different thematic maps draped over the Digital Terrain Model of the portions of territory involved, with particular attention to the selection of the most

up-to-date and representative geological or geomorphological maps available.

The choice has been driven in first place by the scale involved (in terms of extent of the land crossed by each stage), and by data availability. In many cases, only old maps at 1:100,000 scale were available, often showing evident differences in colors, even in neighboring tables. We have chosen to maintain such differences, also in order to stress the problem of uniformity in vast-scale mapping projects. In technical terms, the 3D rendering has been implemented by overlaying thematic and topographic layers over the DTM, using two products of the ESRI "family": Arc Scene and Arc Globe. A "fly-through" video has been prepared trying to highlight the main features of the land; obviously, the most effective results have been obtained in mountain stages, although interesting cues for a geological/geographical readout of the land have been offered also by flatter stages. As a further development of the

project, we are planning to extend the processing to a more specific "3D geological modeling", displaying the information on the "underground" gathered from the available sources at the national or regional Geological Surveys.

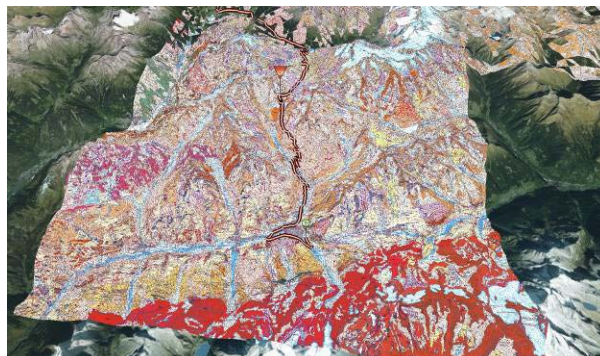


Figure 1 – screenshot from the 3D rendering of the geological map (1:50,000 CARG) over a mountain stage of Girod'Italia 2014.

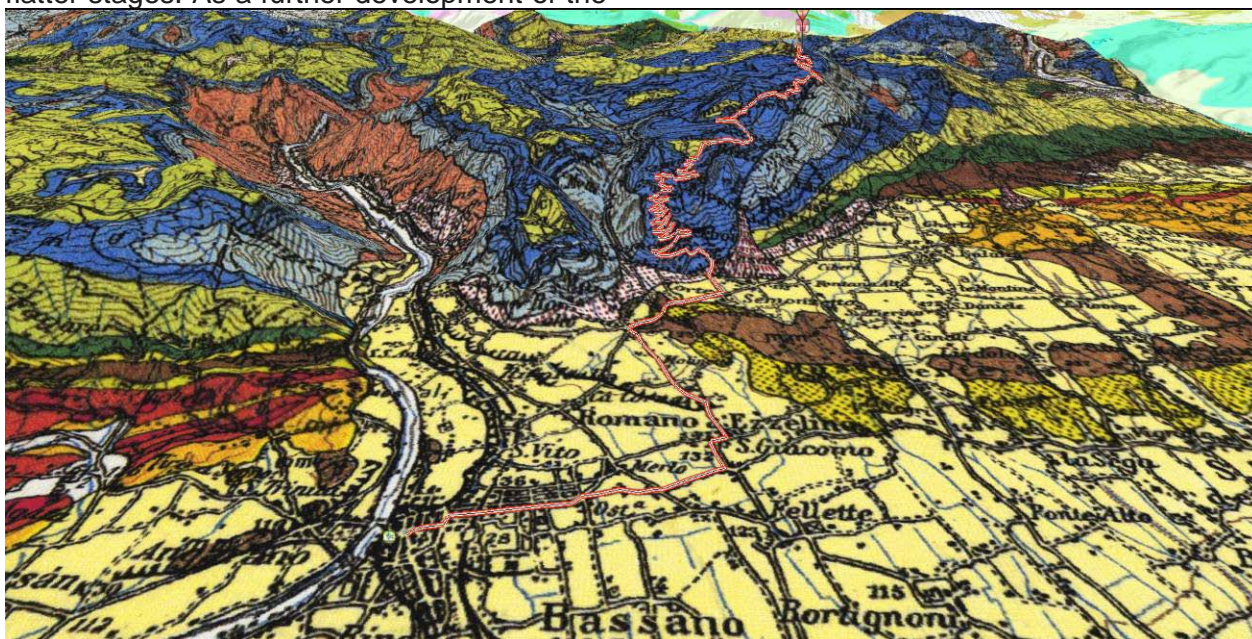


Figure 2 – As in Figure 1, with a 1:100,000 geological map

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## 3D GEOLOGICAL MODEL OF THE CENTRAL PO PLAIN (ITALY): SUBSURFACE GEOPOTENTIALS VS GEOLOGICAL HAZARDS

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**KEY WORDS:** 3D modelling, geopotentials, active tectonics.

### INTRODUCTION

The 3D modelling of buried geological structures, especially in large plains (e.g. Molasse and Po Plain basins), become a strategic objective for the evaluation and sustainable management of the subsurface in terms of resources (water, geothermal energy, oil and gas) and potential usages (storage activities). At the same time, despite the common perception that plain is equivalent to stable, the societal and industrial activities in these areas have to face also geological hazards. As a matter of fact, some of the geological structures hosting geopotentials can generate earthquakes or can be affected by vertical soil movements.

This contribution describes the 3D modelling strategies and the analysis workflows supporting

the evaluation of potential risks and presents the results of the activities within the EU funded GeoMol Project (Alpine Space Programme, Diepolder et al. 2014).

### GEOPOTENTIALS AND NATURAL HAZARD: AN ITALIAN EXAMPLE

The Emilia seismic sequence of May-June 2012 ( $M_w$  max 6.1) hits the central part of the Po Plain, one of the largest plain areas in Europe, highly populated and with important industrial facilities; its underground hosts the Southern Alps and the Emilia-Ferrara thrust systems. The blind thrusts which generated the earthquake sequence are associated with anticline structures hosting exploited hydrocarbon plays (Mirandola area, in Fig. 1).

This case highlights the basic need of a publicly available 3D geological model and of analysis tools to support the decision-makers and facilitate the public acceptance of subsurface uses.

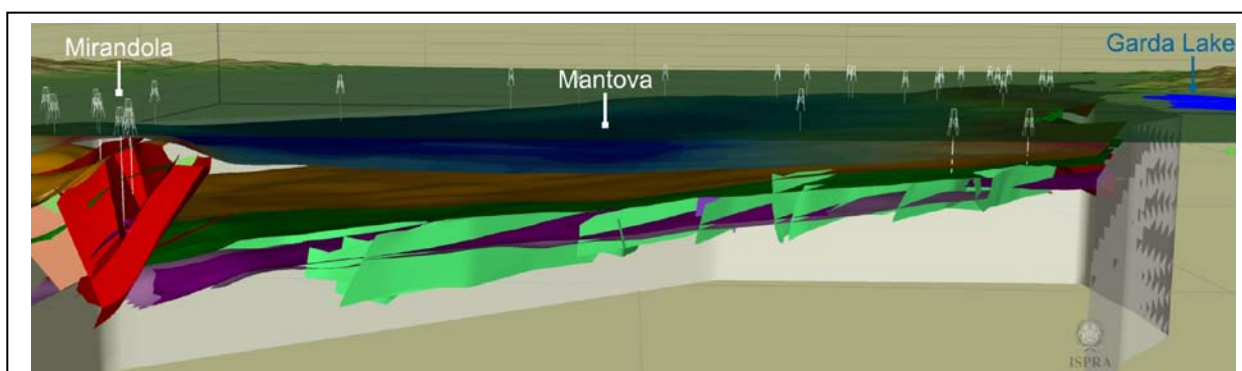


Figure 1 – Slice of the 3D model of the Italian pilot area in the GeoMol Project. View from east; red surfaces are thrusts of the Northern Apennines, light green surfaces are extensional faults; other surfaces are main horizons, from Trias up to Pleistocene.

### 3D MODELLING WORKFLOW

The 3D model for the Italian GeoMol pilot area has been built by the Geological Survey of Italy

(ISPRA) and is based on the interpretation of a wide dataset of seismic lines, provided by the main Italian oil company (ENI S.p.A.) and performed by all the Italian Project Partners, and on the analysis

of deep and shallow boreholes, further investigated by Regione Lombardia and CNR-IGAG to better constraint the age of Pleistocene units.

In the GeoMol Project we define the following three steps modelling workflow (Maesano et al. 2014):

- construction of a "raw" 3D model, using data in time domain and a quick check of well markers to test different 3D velocity models;
- depth-conversion of horizons and faults, using an instantaneous 3D velocity model (Marsden, 1992);
- refining of the 3D model in depth with all the available information (well logs and gravimetric data).

The final model of the Italian pilot area will be available through the GeoMol website [www.geomol.eu](http://www.geomol.eu).

## APPLICATIONS

The GeoMol 3D model is the base for different type of applications. The first use of the model has been the reconstruction of the underground temperature for geothermic purpose, elaborated by the Geological Survey of the Regione Emilia Romagna (Molinari et al., this volume).

A second application of the 3D geological model is to support the risk evaluation within the identification and analysis of tectonic structures deemed to be active: during the 3D model building, ISPRA collaborated with the Istituto Nazionale di Geofisica e Vulcanologia (INGV) to address this task. As a result, the 3D model has provided new constraints for the geometric description of already known seismogenic sources and supported the identification of new ones that will be included in the updated DISS (Database of Individual Seismogenic Sources, DISS Working Group, 2010). On the other side, the INGV contribution provided a detailed classification of thrust faults based on their activity.

The 3D modelling techniques, as opposed to the 2D one, allow to consider the full spatial variability of the kinematic (e.g. slip rates) and geometric parameters of the faults (Maesano et al. 2015) and allows also the identification of elusive tectonic deformations in areas where the sedimentary processes are generally predominant on the tectonic effects.

Another possible use of the GeoMol 3D Model is as an independent, public source of geological information within the Environmental Impact Assessment of subsurface utilisation projects, often based only upon data provided by the proposers.

## CONCLUSIONS

The 3D modelling techniques are commonly recognized as the best synthesis to understand, characterize and describe the geological structures, thanks to the integration of various types of data (e.g. geological, geophysical, geochemical, etc.); collectively, these information provide the foundation in analyzing and monitoring the geological structures, both for their possible geopotential usage and for the hazard they can generate. The final product of the Project is an example of the fruitful collaboration between Geological Surveys, Research Institutes and industrial Companies, that produced an output freely accessible to the public that can be used as the starting point for different types of analysis in different fields, from the scientific research to the administrative decision making.

## ACKNOWLEDGEMENTS

The project GeoMol integrates partners from Austria, France, Germany, Italy, Slovenia and Switzerland and runs from September 2012 to June 2015. The project is co-funded by the Alpine Space Programme ([www.alpine-space.eu](http://www.alpine-space.eu)) as part of the European Territorial Cooperation 2007-2013. For further information please refer to [www.geomol.eu](http://www.geomol.eu)

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## A 3D MODEL OF THE NORTH GERMAN BASIN – CHALLENGES AND APPROACHES

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**KEY WORDS:** 3D model, North German Basin, TUNB, gOcad, geologic survey organisations.

### INTRODUCTION

Germany is a densely populated, highly industrialised country with a long tradition in utilising the deep subsurface, e.g. as a source of raw materials, as storage space for fossil fuels, and for the disposal of waste. In recent years, the interest in the deep subsurface even increased, not least due to discussions on new technologies such as carbon dioxide capture and storage, storage of renewable energy based on compressed air and hydrogen, and an increasing demand for geothermal energy production. Today's options related to production and storage of conventional as well as renewable energy involve potential conflicts of use and necessarily triggered the discussion on the need of a subsurface planning policy.

In Germany, the responsibility for geoscientific issues on the subsurface, including e.g. the compilation of basic geological information, is a matter of the federal states and their state geological survey organisations. The Federal Institute for Geosciences and Natural Resources (BGR), however, is an institution advising the German Federal Government. The German geologic survey organisations (GSOs) cooperate on issues spanning beyond the federal state level. A recent example for this cooperation was the development of the Storage Catalogue of Germany, by all GSOs in 2011, focussing on the identification and characterisation of reservoir and barrier rocks for storage of e.g. carbon dioxide (Müller & Reinhold 2011).

The growing focus on the deep subsurface raises the need for more detailed geological information. Geology is inherently a 3-dimensional issue and today's computing technology allows the development of large scale 3D geological models. Several German federal states have already developed 3D geological models of their area of responsibility ([www.infogeo.de](http://www.infogeo.de)). However, harmonised 3D geological models beyond the federal state level are still sparse and available only for the Upper Rhine Graben ([www.geopotenziale.org](http://www.geopotenziale.org)) and under development for the Molasse Basin ([www.geomol.eu](http://www.geomol.eu)).

### A NEW JOINT PROJECT

In 2014 BGR and the GSOs of the northern German federal states started the project “Subsurface Potentials for Storage and Economic Use in the North German Basin (TUNB)” with the primary intention to construct a 3D model of the North German Basin (NGB) within a period of six years. The NGB is the largest and deepest sedimentary basin in Germany, see Fig. 1.

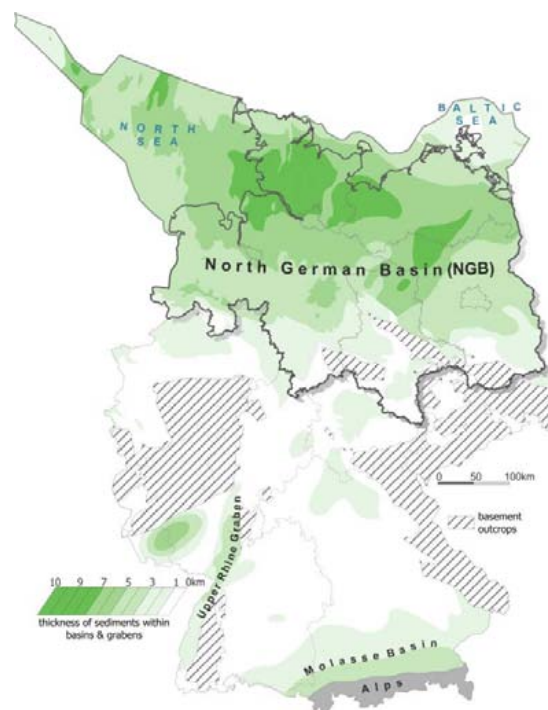


Figure 1 – Deep sedimentary basins and grabens in Germany (green areas). A 3D geological model of the NGB will be constructed within the joint project TUNB.

### PREVIOUS WORK AND CHALLENGES

Atlases with structural contour and isopach maps as well as 3D geological models are available for parts of the NGB. The “Tectonic Atlas of Northwest Germany and the German North Sea Sector”, GTA (Baldschuhn et al. 2001) covers the western part of the NGB. It contains structural contour maps (the base of 14 lithostratigraphic units). This atlas has been transferred to individual 3D geological models, e.g. for the central German North Sea sector (Kaufmann et al. 2014) and for



the federal state of Lower Saxony (Bombien et al. 2012).

The Geophysical Atlas of the German Democratic Republic, GPK (Reinhardt et al. 1960-1991) covers the eastern part of the NGB. It contains structural contour and isopach maps of the most prominent seismic reflection horizons. Based on this atlas, a 3D geological model for the federal state of Brandenburg has been constructed.

These existing atlases, 3D models, and exploration data are the basic information available for

the construction of the NGB 3D geological model. However, distribution and quality of the exploration data is highly heterogeneous. Moreover, as the atlases and existing 3D geological models are based on different velocity models and the horizons are based on different interpretation and modelling concepts (the base of lithostratigraphic units vs. seismic reflection horizons), inconsistencies occur, particularly along the former inner German border (Fig. 2).

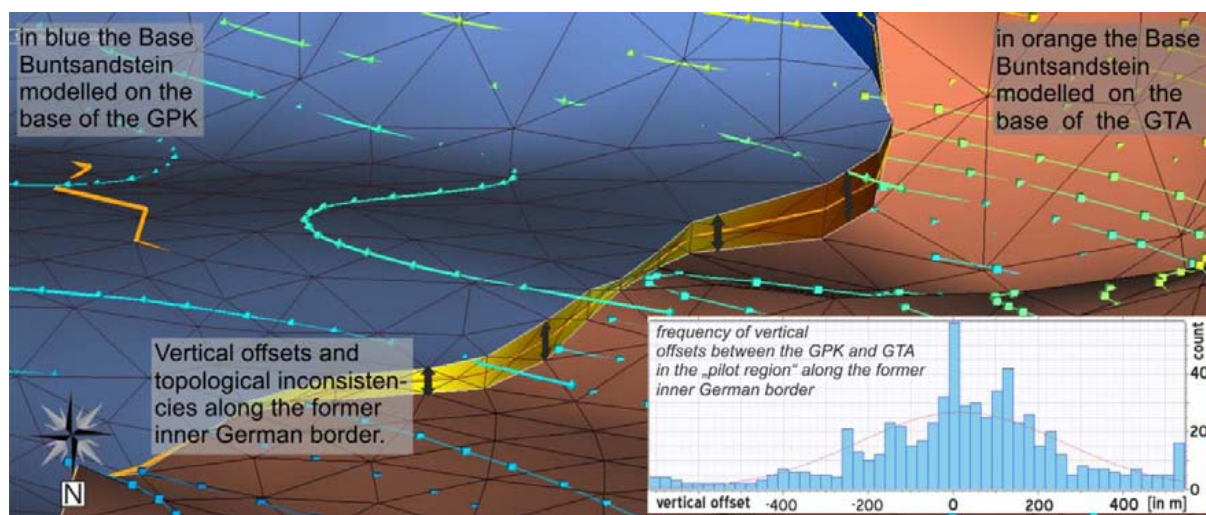


Figure 2 – Example for major inconsistencies between existing model horizons. The vertical displacement of the base Buntsandstein horizon at the former inner German border. The offset can add up to hundreds of meters.

### 3D MODELING APPROACH FOR THE NGB

The GSOs of the northern German federal states will construct 3D geological models of their area of responsibility as components for the entire NGB 3D model. BGR will construct 3D models of the exclusive economic zone in the German North Sea and the Baltic Sea sector. BGR coordinates these efforts and finally merges the individual models into one consistent model of the NGB. In order to ensure that the individual models fit to a consistent 3D model, three working groups have been established. The working groups will elaborate stratigraphic details of the 13 model horizons, a concept for the interpretation and generalisation of horizons, faults and salt structures, and finally specific technical issues concerning the use of the gOcad modelling software. The concepts developed by the working groups will be tested and applied to a small region, the so-called “pilot-region”, where five federal states lie in close proximity to each other at the former inner German border, south-east of Hamburg.

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## STEPS TOWARDS A 3D MODEL OF THE GERMAN BALTIC SEA AREA – COLLABORATION WITH ACADEMIC RESEARCH IN THE USO PROJECT

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**KEY WORDS:** *Baltic Sea, Mecklenburg-Western Pomerania, Germany, offshore 2D seismic, Rügen Caledonides, North German Basin Tornquist-Teisseyre Zone, VPSS.*

### THE USO PROJECT

The Geological Survey of Mecklenburg-Western Pomerania (LUNG M-V) and the University of Greifswald started in 2012 the research project USO (“Untergrundmodell Suedliche Ostsee”). Numerous seismic profiles, measured in the 1970ies and 1980ies by the organisation “Petrobaltic” (a joint venture of former East Germany, Poland and the Soviet Union; REMPEL 1992) are used together with a few offshore borehole data to create a 3D structural model of the subsurface of the southern Baltic Sea area. These seismic data were partly re-processed by the Federal Institute for Geosciences and Natural Resources (BGR) during the SASO project (“Strukturatlas Suedliche Ostsee”; SCHLUETER et al. 1997) and by the Central European Petroleum Ltd. (CEP). Major lithostatigraphic units, tectonic faults, salt pillows, potential oil reservoirs and gas storage systems will be visualized to support politicians and decision makers in underground space management. The project area is divided into an eastern and a western part (Fig. 1), modelled separately.



Figure 1 – Investigation areas of the USO project in the southern Baltic Sea.

### GEOLOGICAL EVOLUTION OF THE SOUTHERN BALTIC SEA AREA

The subsurface geology of the southern Baltic Sea area between Denmark, Sweden in the north and Germany and Poland in the south comprises Mesoproterozoic granites and gneisses of the East European Craton. These crystalline basement rocks are overlain by Cambro-Silurian sediments, which were deposited at the south-western margin of the palaeocontinent Baltica. Due to collision with the terrane Avalonia during Ordovician and Silurian times, these rocks were overthrust by deformed and slightly metamorphosed marine sediments, mainly of Ordovician age. After this Caledonian orogeny, Devonian and Carboniferous shallow water deposits were accumulated, which are only locally preserved, especially between Rügen and Usedom Islands (KATZUNG 2004).

A short phase of Permo-Carboniferous rift magmatism was followed by large-scale subsidence that led to the formation of the North German Basin (NGB) as part of the Central European Basin System. The Middle Permian to Triassic sediment succession show a decreasing thickness towards the NE according to the outline of the north-eastern margin of the NGB. In contrast, the thickness of Upper Cretaceous sediments, mainly composed of chalky limestone, is highest north-east of Rügen Island.

The investigation area is characterized by different Palaeozoic and Mesozoic fault systems. They were mainly formed by extensional and transtensional movements in the Late Permian to Early Triassic and Late Triassic to Jurassic times, respectively, resulting in horst and graben structures. Reactivation of these faults during compressional tectonics in Late Cretaceous times led to formation of inverted anticlines. The major tectonic fault system of the Tornquist Line is accompanied by numerous NW to WNW trending faults forming the Tornquist fan widening towards the west (THYBO 2000). Furthermore, local Mesozoic graben structures are bordered by en-echelon faults of the so called Vorpommern-Störungssystem (VPSS; KRAUSS & MAYER 2004), which are mainly NNW–SSE oriented.

## INTERPRETATION AND VISUALIZATION OF THE SEISMIC PROFILES

86 re-processed seismic profiles in an area west of Ruegen Island with a whole length of about 1500 km and 150 profiles with a total length of about 3120 km north-east of Ruegen and Usedom Islands were used.

In a first step, important marker horizons and faults were picked using the "SeisWare" software package. Due to crosscutting lines, this allows a quality control like the consistence of each picked horizon.

Afterwards, these horizons were gridded using Kriging. Comparing the results with older distribution and time structure maps of several horizons allows to discuss a revised structural pattern for the investigation area.

Finally, the gridded marker horizons as well as tectonic structures and triangulated faults could be visualized using the "SeisWare 3D - Visualizer".

## FUTURE WORK

In a next step, it is planned to transfer the time-based horizons into depth-based layers. Afterwards, all generated surfaces and triangulated fault systems will be integrated into a GOCAD 3D model. Correlation with geological units and structures in the neighbouring countries of the Baltic Sea region could be the approach of an EU funded research project.

## ACKNOWLEDGEMENTS

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## THE LIMITS OF INTEROPERABILITY – MODEL FUSION NEEDS MORE THAN TECHNICAL SOLUTIONS

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**KEY WORDS:** 3D-modelling, transnational collaboration, interoperability, semantic harmonization, model delivery.

### THE CHALLENGES OF TRANSNATIONAL 3D-MODEL BUILDING

One principal objective of the GeoMol project, implemented by an international consortium, is to build up a seamless 3D geological model of the Alpine Molasse Basin, down to more than 5 km to serve transnational geopotential assessment (e.g. Diepolder et al. 2014). A major challenge in 3D modelling at great depths is the availability of data with an adequate distribution and resolution to address issues properly. Even though several 3D geological models of parts of the Molasse Basin have been built in the past (e.g. Rupf and Nitsch 2008, Pamer and Diepolder 2010, Sommaruga et al. 2012), the merger of existing 3D geological models by just filling the gaps in between is not feasible: they are made for different purposes and address distinct issues, and are based on different primary data originating from multiple sources with various dates of origin. Thus, preparing coherent 3D information imperatively requires harmonization from the very beginning of the model building process applying consistent methods and common parameters.

Harmonization of 3D subsurface data from different sources is controlled by three major constraints: technical issues, methodological or structural agreements and legal requirements. While the technical aspect can be solved by software developments or sophisticated databases, the common understanding of fundamental geological concepts like stratigraphy, naming and the selection of appropriate modelling methods (normally developed for distinct geological settings only) is troublesome and, astonishingly, not yet based on a mutual geological understanding. Legal constraints are beyond scientific influence but do control the other two aspects significantly.

### TRANSNATIONAL HARMONIZATION

GeoMol as a transnational project with a multinational and multi-sectoral partnership developed several strategies to cope with various obstacles in

technical and semantic harmonization either by technical solutions or by pragmatic approaches.

Disparate data policy and data ownership are most obstructive for transnational model building and model share: Some partners do have access to all base data ever surveyed within their territory whereas in other countries use of baseline data is limited to a few single data subsets – resulting in a imbalanced and inconsistent data input (Figure 1). Further disparities apply to the depiction of the used data sets e.g. as an indicator for model uncertainty. At some partners even metadata may be displayed in a very vague way only. To comply with the legal requirements on a transnational level demands many concessions and in parts an oversimplification of the products provided for public access.

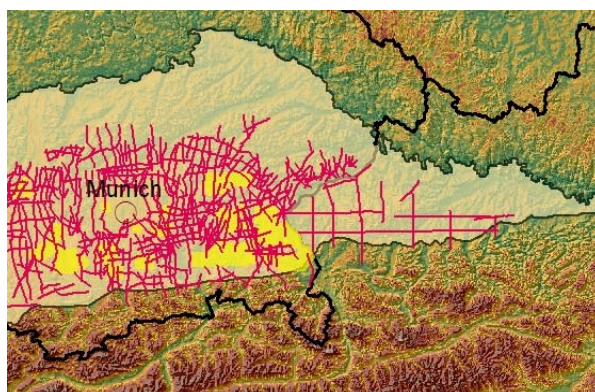


Figure 1 – A part of GeoMol's model area and comparison of seismic baseline data available for modelling input in Bavaria (left) and Austria (right) – red: 2D seismic sections, yellow: 3D seismic projects.

The geological, resp. stratigraphic subdivision of the Alpine Foreland Basins has evolved from regional approaches and reflects the complex basin evolution featuring sedimentary cycles varying in space and time. Grown historically differing nomenclatures and subdivisions on the detailed scale are used. Thus, working cross-border also requires a semantic harmonization and the alignment of stratigraphic peculiarities to allow the correlation of a uniform litho-stratigraphic subdivision with the prominent seismic reflectors traceable over the entire basins. The harmonized litho-stratigraphy also serves uniform model building between and beyond the seismic

reflectors, e.g. by using regionalized thickness constraints derived from borehole information.

Concerning the seismic data as the crucial input for structure modelling it is imperative to standardize all technical parameters and content prior to further analysis exploiting the technical advances in seismic processing: an effort has been made to adjust all lines to the same seismic reference level, amplitude and step of signal processing to avoid mismatching at intersections and at the country borders (Capar et al. 2013). Where technically feasible and geologically reasonable common or aligned velocity models for time-depth conversion were calculated.

Making use of advanced database technology, GeoMol implemented a new web-based data base capable of managing and visualizing 3D-objects in a multi-user environment in line with the users' needs (Gabriel et al. 2011). Technically, the system handles a distributed organized (owed to legal mandates) data storage, performs on-the-fly coordinate transformation and is the second backbone besides the classical 2D-map viewer for dissemination of GeoMol's outcomes (Figure 2).



Figure 2 – GeoMol's web-based 3D viewer portraying the fault network of two 3D geological models of the cross-border Upper Bavaria – Upper Austria area (screen dump of the beta version). The two 3D models displayed are stored separately at the legally mandated geological survey organizations and merged on-the-fly via the web (from Diepolder & GeoMol Team 2014).

### LESSONS LEARNED

Besides the essential technical solutions like the distributed organized and hub connected data base, the transnational share of 3D-geological models is fundamentally depending on a common understanding of the conceptual and stratigraphic framework and must be driven by the readiness to overcome discrepancies in a pragmatic, result oriented way. This was achieved by a drastically reducing the complexity and the limitation to only few basin wide horizons. At a smaller scale concepts were amalgamated and horizons could be merged.

The consideration of the legal restrictions each partner is liable to has to be done in an early project stage in order to define viable products for dissemination. Another prerequisite for effective harmonization through cooperation is the frequent exchange among all project partners to foster personal contacts and the common understanding of the issues to be solved. Even though some parts of the work were outsourced to private companies or universities, these partners were also continuously incorporated into the project's meetings and hence a decision making process ensuring a seamless and consistent data and work flow.

### ACKNOWLEDGEMENTS

The project GeoMol is co-funded by the Alpine Space Program as part of the European Territorial Cooperation 2007-2013. The project integrates partners from Austria, France, Germany, Italy, Slovenia and Switzerland and runs from September 2012 to June 2015. Further information, maps and 3D models are available on [www.geomol.eu](http://www.geomol.eu).

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### 3D geological modelling in Canada: Challenges and opportunities for academic research

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**KEY WORDS:** 3D geological models, Canada, data integration, natural resources, geohazards.

to study subsurface geology in an urban environment.

#### INTRODUCTION

Three-dimensional geological modelling programs can spur innovation in geosciences, computer sciences, and engineering. Academic research in partnership with government or industry and involving 3D geology includes studies of 1) regional groundwater systems or contamination problems, 2) geohazards, 3) potential nuclear waste repository sites, and 4) natural resources. These studies often focus on complex geoscience problems requiring a high level of data and knowledge integration, as well as considerable collaborative research and development (R&D).

The purpose of this paper is to examine the state of three-dimensional geological modelling in Canada, with a focus on modelling problems that have involved academic research in collaboration with government or industry.

#### GOVERNMENT-ACADEMIA 3D MODELLING STUDIES

In Canada, geological surveys have developed ambitious 3D mapping programs with varying levels of collaborative research with academia (Table 1). Many of these programs are motivated by the need to improve understanding of groundwater systems and resources at watershed or regional scales (e.g. Ross et al. 2005; Tremblay et al. 2010) or for seismic zonation in cities (Leboeuf et al., 2013). This has set priorities as to where the mapping efforts would take place and at what scale. Most regional models extend across urban, semi-urban, and rural areas. Commonly, the data and knowledge needed to develop these models have been acquired over several decades by various organizations – geological surveys, municipalities, consulting or engineering firms and universities – with no common infrastructure (cf. Karrow and White 1998). This is one important challenge common to most projects, which is exacerbated in large urban areas (e.g. Greater Toronto Area) because of the many organizations involved in collecting data as well as the difficulties



Figure 1 – Canadian localities mentioned in the text.

Area	Model	Size/scale	Access	GRD
Montreal Region	Layers/grids (0-100m)	1:50,000	Theses, CDs, Local IT	MSc and PhD
Quebec City	Layers/grids	1:50,000	idem	PhD
Chaudiere	Layers/grids	1:100,000	idem	PhD

Table 1 – Selected examples of 3D models developed through gov.-academia collaboration. GRD: academic level.

Government and university-based mapping groups have mainly focused so far on the main bounding surfaces of Quaternary units that can be mapped at regional scale, as well as the underlying bedrock topography (Fig.2). Borehole data from various sources have been examined for accuracy, reliability and potential errors using different approaches.

Because of their broad scale, regional models that have been developed so far by geological surveys and academia generally do not include sedimentological or physical properties (e.g. mean grain size, porosity), even when such data had been collected locally for academic research. However, end-users may locally downscale models, build grids, and populate them with

properties for their specific needs drawn from research outputs (e.g. Ross et al. 2005).

### INDUSTRY-ACADEMIA COLLABORATIVE 3D MODELLING

This type of collaborative research may be developed in various fields; one of them is mineral exploration, which is increasingly focused on deeper targets in mature mining camps or challenging terrains where mineralized zones and potential ore deposits are buried under thick sediment cover or regolith.

New methods are needed to explore for mineral resources in these terrains and academia is part of

this effort in partnership with industry. Using known buried mineralized or related alteration zones, the purpose of 3D modelling is to identify geochemical or mineralogical assemblages through the stratigraphy that have been dispersed from these buried zones. These 3D modelling projects involve the development of stratigraphic grids and integration of sedimentological, geochemical, and geostatistical results.

The goal is to develop enhanced exploration approaches that will allow detection of the subtle distal footprint of a buried orebody, and hence may guide exploration drilling programs.

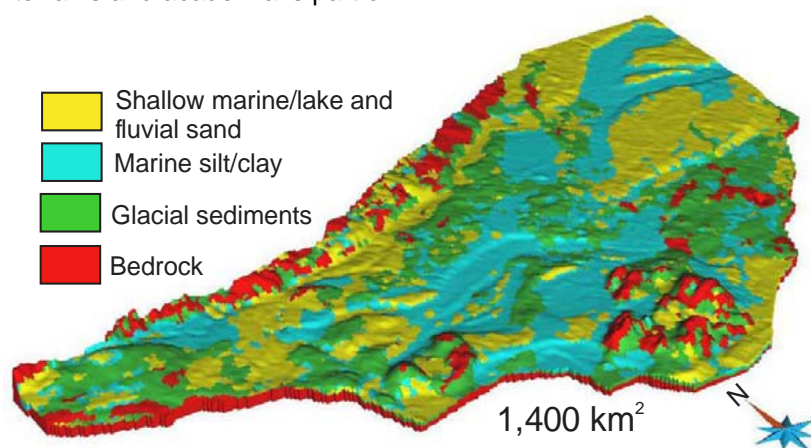


Figure 2 – Example of a 3D geological model (simplified and upscaled version) developed through govt.-academia collaboration as part of the National Groundwater Program of Canada (adapted from Ross et al. 2005)..

### CONCLUSION

Canada is a large country with diverse geology and a wide variety of 3D geological modelling needs. Urban geology is needed in some areas because of rapid urban growth or for assessing vulnerability of buildings and infrastructures to natural hazards. Furthermore, natural resources are an important part of Canada's economy and research involving 3D geological modelling is contributing, for example, towards development of new exploration techniques to find deeper, more elusive, mineral resources. There are also major concerns about the use of water resources, the protection of the natural environment, and our capacity to respond to natural disasters or to infrastructure failures (e.g. pipelines). These issues are complex and sensitive; nonetheless, the lack of easy (open) access to academic research results and other reliable geological information in three dimensions contributes to the problems in many regions. There is an urgent need in Canada to put more effort into supporting integration and processing of large datasets from different sources, developing standards and web service technologies to deliver integrated 3D

geological information in a timely and efficient manner. These tools and applications are being developed by collaborative research involving academia, government, and industry.

### ACKNOWLEDGEMENTS

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## 3D geological information for professionals and the public – Two examples for providing target group based data sets by the State Geological Survey of Baden-Württemberg (Germany)

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**KEY WORDS:** 3D-Modelling, information system, web services, shallow geothermal energy, geopotentials, Baden-Württemberg, Upper Rhine Graben

### Introduction

Since 2007, the State Geological Survey of Baden-Württemberg (LGRB) has been developing medium-scale geological 3d models. They represent a central, digital and updatable data base for principle geological issues as well as applied aspects. Derived spatial information is provided via web-services for professionals like project developers as well as policy-makers, licensing authorities and the interested public. This user groups have different demands on geological data sets and derived information like the assessment of geothermal potential and drilling risks. While professionals ask for quantifiable data sets, policy makers and the interested public expect translated, easy understandable information like maps with traffic signal classes. Therefore, data sets from geological 3d-models are prepared according to specific target groups. The presentation shows two internet applications for the use of shallow geothermal energy (ISONG) and the assessment of geopotentials in the deep Upper Rhine Graben (GeORG).

### Information system for shallow geothermal energy (ISONG)

The intensive use of shallow geothermal energy during the last ten years generated an urgent need for reliable geological underground information, in order to plan geothermal projects, to protect groundwater resources and to avoid drilling hazards. For that reason LGRB developed a state-wide and web-based information system, called ISONG ([www.geothermie-bw.de](http://www.geothermie-bw.de)) which provides information about geothermal properties and drilling risks for approving authorities, planners and house builders.

Centerpiece of the information system is a geological 3d model. It reproduces the position of

up to 24 different geological modelling units, which vary in terms of petrography, hydrogeology and geotechnical risks. 3d information is stored in a PostgreSQL database based on grids with a 100 m resolution. The internet application accesses the database and provides information about geothermal efficiency as well as restrictions for borehole heat exchangers (e.g. water protection areas) and drilling risks (e.g. artesian aquifers and sulfate bearing rock units). The extended version additionally provides a prognostic drilling profile up to depths of 400 m and assessment of heat extraction rates for different depths.

### GeORG geoportal for geological potentials of the deep Upper Rhine Graben

The Upper Rhine Graben with its complex geological history presents multiple opportunities for the use of its geopotentials. Possible uses include among others deep geothermal energy production, CO<sub>2</sub> sequestration and the storage of compressed air. In the framework of the European project dubbed GeORG and financed by the Interreg IV Upper Rhine program from October 2008 to December 2012, partners from Switzerland, France and Germany generated a harmonized, transnational geological 3d model as well as a geostatistical temperature model. Information about basic geological aspects and derived geopotentials is freely available on the GeORG geoportal ([www.geopotenziiale.eu](http://www.geopotenziiale.eu)). It contains besides a mapviewer an extensive metadata catalogue.

The GeORG mapviewer is an interactive web mapping application, where project results can be searched, spatially visualized and queried. It also allows for dynamic generation of vertical and horizontal geological sections and prognostic drilling profiles.

GeORG metadata provides information on the availability of spatial data as web mapping services (WMS), about the access to these WMS and restrictions of use. The metadata profile complies with the requirements of the EU directive INSPIRE and national spatial data infrastructures.



## A TEAM COLLABORATION TOOL AND PLATFORM TO SHARE 3D GEOMODELS

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**KEY WORDS:** *3D geological subsurface models, management of 3D geomodels, GST.*

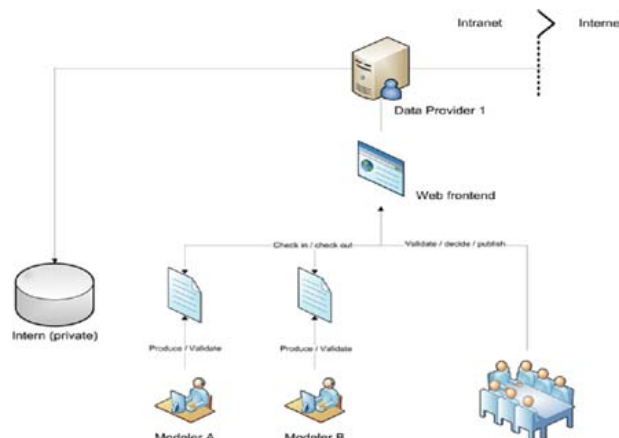
### INTRODUCTION

An indispensable prerequisite of team collaboration is shared accessibility of common data and efficient exchange of information. For textual data like documents, spreadsheets or slide presentations online collaboration tools are already available (e.g. Google docs, Microsoft 360° Office, etc.). Sophisticated software packages exist to construct 3D digital geological models of the subsurface but collaborative tools to exchange geomodels and their constituting geobjects and corresponding geodata are yet to be developed and implemented. The initial data comprise as diverse data as surface and borehole data, geochemical observations, geological maps, interpreted (processed) geophysical data, remotely sensed data, and others. Continuous collection of these data results in an ever growing amount of available data to be included in any Earth modeling. Additional data should initiate consistency checks of existing models and may require their revision. They may also provide data to refine existing models with respect to their spatial resolution. Since geomodeling is more and more often a team effort like in GeoMol (<http://geomol.eu>), tools to update geomodels, to document and communicate the changes and to discuss the reasoning behind the revision in a systematic manner like tracking changes with comments in a WORD document are required (Apel, 2006; Pouliot et al., 2008).

### A TEAM COLLABORATIVE TOOL FOR 3D GEOMODELS

Geomodeling, i.e., constructing and editing of 3d digital geomodels is done with highly sophisticated commercial software. Then the geomodel and its components are usually stored in a proprietary format in binary or ASCII files organized in a file system. Our generic data model "Geosciences in Space and Time" and the corresponding software GST have been designed

to manage complex 3D geomodels of the subsurface, i.e., their constituting objects and corresponding data in a database. For that purpose the proprietary data format is transformed into a generic format. Once stored in the database, all of its functionality applies. Thus it permits different users simultaneous access to the geomodel or parts thereof. It provides means to check-out and check-in parts of the geomodel thus facilitating their updating or refining (Figure 1). Elaborating on dedicated volumes of special interest allows to generate complex models with an increasing level of detail.



*Figure 1 – Scheme of both cooperation of expert geoscientists modeling the common geomodel and task sharing between geoscientists and policy makers.*

### CHECK-IN/CHECK-OUT – SEAMLESS 3D TILES

To facilitate updating or refining geomodels which are large by their spatial extent or by their level of detail, GST provides functionality to check out several 3D tiles at the same time, change their contained portion of the 3D geomodel, and preserving the overall consistency of the entire geomodel when the tiles are checked in again.

### MANAGEMENT OF EVOLVING VERSIONS

Version management systems like SUBVERSION or GIT and others have been developed in order to enable tracking of changes within a multi-user

environment. Version management includes storage of the author and the date (time stamp) of the changes as well as the storage of the new version without duplicating the data in order to avoid both redundancy and shortage of physical storage capacity. Thus it is possible to revert to a specified previous version if later versions do not apply, e.g. because they are erroneous. Of course, version management is useful in the realm of 3D geomodeling as well (Le, 2014). One

way to look at it is in terms of monitoring the advance of information, change of paradigm, and eventually progress of knowledge including trial and error. Version management may also be applied to compare a temporal sequence of predicted states of a geosystem realized in 3D digital geomodels with the actual evolution of the geosystem.



Figure 2 – 3D boxes containing subsets of the geomodel of the subsurface can be selected using the 2D web mapping application (center), and then appropriately and efficiently visualized. A modeled property like temperature can be displayed in vertical cross sections slicing the 3D box, and a geological map at a given depth can be displayed as a horizontal cross section within the box (left). The portion of the 3D geomodel within the box can be visualized as interactive WebGL scene (right) and instructively inspected without any additional visualization software.

## MODUS OPERANDI

Within the EU project GeoMol, GST enables the participating state geological surveys to cooperate across boundaries towards a unique subsurface model of the Alpine Molasse Basin. Additional legal and political constraints like divergent national data policies of several partners come into conflict with the pragmatic objective to store corresponding geomodels in a common (central) place. To meet these non-technical requirements GST instances are integrated individually into each partner's IT environment. Then the cross border interaction of the models is realized through a service oriented architecture (SOA). Thus GST provides means to share geomodels and their constituting data while they are hosted and maintained by each partner individually. A central access point is setup through the web browser application GST Web. It connects the individual service sites and allows to access the geomodels or portions of them not only by the cooperating partners but also by the interested public. GST Web combines conventional 2D web map service techniques with state of the art 3D real-time visualization technologies (Figure 2).

## ACKNOWLEDGEMENTS

The project GeoMol is co-funded by the Alpine Space Program as part of the European Territorial Cooperation 2007-2013. The project integrates partners from Austria, France, Germany, Italy, Slovenia and Switzerland and is active from September 2012 to June 2015. Further information on <http://geomol.eu>.

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## 3D geological model to support the management of urban subsurface environment:

### Bucharest City case study

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**KEYWORDS:** 3D geological model, sedimentary environment, spatial database, software platform, urban infrastructure.

continental) ending with Quaternary sediments (Figure 1). As a result, different alluvial deposits (such as wetland and lacustrine deposits) can be found.

## INTRODUCTION

The knowledge of subsurface environment is of great importance, particularly in urban areas, where the complexity of the geological settings analysis is further increased by the presence of underground engineering works. Hence, under the continuous expansion (horizontal and vertical) of modern cities, an integrated management of urban subsurface is becoming a necessity. This requires developing tools, methodologies and models allowing to accurately map the subsurface variability.

This paper presents the methodology used to elaborate the 3D geological model of the Quaternary sedimentary deposits of Bucharest City and several urban hydrogeological applications. The methodology is based on the GIS tools developed by Gogu et al. (2011) and on the geospatial database concept (Gogu et al., 2001).

Bucharest City is located in the central part of the Moesian Platform which lies on a rigid base of metamorphites, and various igneous intrusions (granodiorite, granite).



Figure 1 – Geological map of Bucharest City

The sedimentary deposits covering this rigid base are made by different phases of erosion and sedimentation processes (marine, lacustrine, or

## DATA AND METHODS

The 3D geological model of Bucharest City was computed based on a large volume of information comprising of geological, hydrogeological and geotechnical borehole logs (over 1500 boreholes with depth between 5 and 275 m), geological and hydrogeological maps, geophysical logs, digital elevation model (DEM). These data were:

(1) Processed and stored into a geospatial database.

(2) Analysed using a 3D geological modelling instrument elaborated by Gogu et al. (2011). This consists on building 3D geological profiles which were interpreted using litho-stratigraphical criteria.

(3) The resulted processed data (3D geological cross sections) were used to identify the layers of the Quaternary deposits which were then interpolated to delineate the main sedimentary aquifer strata.

(4) The structural maps were then intersected with the geometry of existing urban infrastructure elements (subway network, sewer system).

## RESULTS

The Quaternary sedimentary deposits have been described and organized into 6 structural hydrogeological units, from top to down as follows (Serpescu et al., 2013):

- Superficial deposits represented by loess and anthropogenic materials.
- Colentina Formation made up of poorly sorted, cross-stratified sand and gravel with clay lens. This layer represent the shallow aquifer of Bucharest City.
- Intermediary deposits made of silty-clay with fine sand intercalation.
- Mostistea Formation made of sediments with a variety of grain size, from fine sand to coarse sand with small intercalations of gravels. This layer represent the second Quaternary aquifer of Bucharest City.
- Marly Complex made by a succession of marls and clays with lenticular sandy intercalations indicating a fluvial-lacustrine environment.

- Fratesti Formation made of sand and gravel which includes three aquifer sub-units (A, B and C). This layer represents the deeper Quaternary aquifer of Bucharest City.

The first two aquifer layers have a direct interaction with most of the urban infrastructure: sewer network, subway tunnels and stations, water supply network. By intersecting the 3D geological model (Figure 2) with the aforementioned urban infrastructure elements it has been possible:

- To identify sewer conduits located partially or completely in the upper aquifer unit (showing a high potential of water exchange between groundwater and the sewer system). This was the first step towards the quantitative assessment of water exchange between the aquifer and the sewer system using the conceptual approach developed by Boukhemacha et al. (2015).

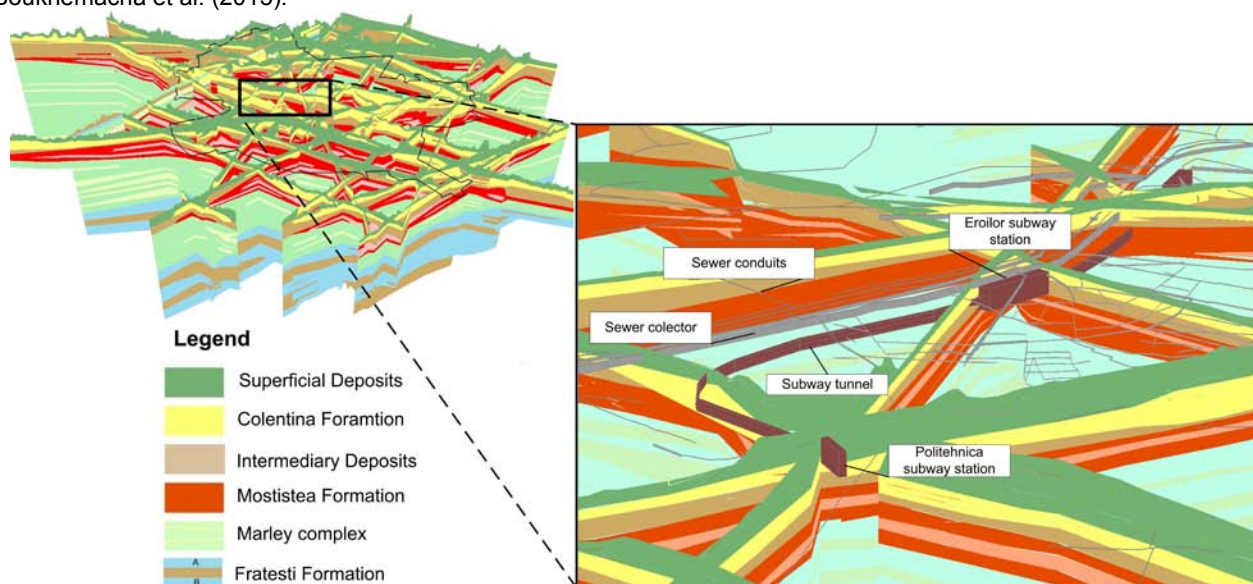


Figure 2 – 3D geological model intersection with the urban infrastructure of Bucharest City.

## CONCLUSIONS

This paper presents the methodology used to elaborate the 3D geological model of the Quaternary sedimentary deposits of Bucharest City and several urban hydrogeological applications. The developed 3D geological model is a reliable support for further hydrogeological and geotechnical studies.

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- To provide the geometrical parameters necessary to assess the barrier effect induced by the presence of underground works (subway infrastructure, underground parking lots, etc.) on groundwater flow (Boukhemacha et al., 2013).

Furthermore, the existing 3D geological model provides the basic input for several urban hydrogeological and geotechnical models elaborated for Bucharest City (e.g. CCIAS 2012, Boukhemacha et al., 2015) used for urban groundwater managing, assessing land surface deformations (as presented in the research project SIRYS [www.ccias.ro/sirys](http://www.ccias.ro/sirys)) and other civil engineering works.

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## Interoperability in 3D Geological projects using Move as a common modelling environment.

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**KEY WORDS:** 3D Model Building, Analysis, Multi-user, Database, INSPIRE, Interoperability, Formats.

### CHANGING DEMANDS FOR GEO DATA

Advances in geological data capture techniques and improvements in computing power are creating an ever growing demand for accurate 3D models. Geologists from all sectors (academic, public and private) are producing and consuming greater volumes of 3D data than ever before. Recent studies indicate that in the era of “Big Data”, the amount of digital data available is doubling every two years (Gantz and Reinsel, 2011). The challenge faced by today’s geo data managers is to provide those users with secure, efficient access to the data they need – irrespective of its provenance. End users must be able to seamlessly access information to answer geological questions without concerning themselves with the way that data was captured and stored. To be most effective, data should follow the guidelines laid out by the INSPIRE directive (2007):

- it should be collected just once and reused;
- it should be seamlessly retrieved from different organisations and data formats;
- it should be scalable;
- it should be transparently available;
- it should be discoverable in terms of availability and usage.

### MOVE AS A COMMON MODELLING ENVIRONMENT

Each organisation has its own particular set of requirements for how data is accessed and used, and its own applications of choice for consuming this data: in this paper, we argue that the Move software can provide a consistent environment, allowing users to consume data from a plethora of sources before making use of industry leading structural modelling techniques and analysis. These sources include traditional flat file GIS interchange formats, but also now include a direct link to a 3D database. We will examine a case-study involving Switzerland’s Federal Office of Topography (swisstopo) and their GeoMol cross border data modelling project. This project demonstrates how Move can be extended to work with innovative new data stores such as GiGa info-systems revolutionary Geosciences in Space and Time (GST) system. By linking directly to the GST system, for the first time, users of Move will be able to:

- store and retrieve data in a 3D enterprise-wide relational database;
- access full or partial features via spatial querying;

- it should be scalable;
- share multi-user edits directly and access the latest changes from other team members;
- publish data internally and externally via a web-interface

The swisstopo GeoMol project uses Move as the geologists access point for cross-border data covering the Alpine Foreland Basin area in 6 national areas. The link has been specifically tailored to meet the exacting requirements of the development of this model. In addition, the legally mandated swisstopo data model has also been supported by the link – ensuring that the data complies with the INSPIRE directive and will be fit for all use cases. Move communicates with GST Storage via an Application Programming Interface (API) and external users will be able to access data directly via swisstopo’s GST web interface (see figure 1)

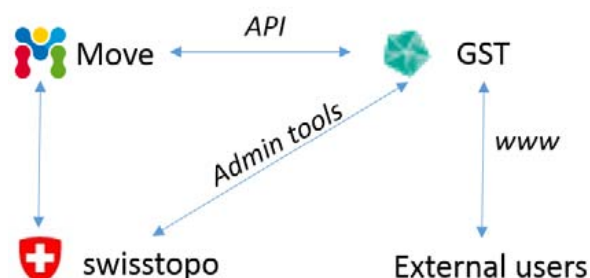


Figure 2 – Project structure

### FOCUS ON INTEROPERABILITY

The Move-GST link is one example of an array of systems which can be accessed from Move and illustrates how our focus on interoperability facilitates the development of brand new data linkages as required. This paper illustrates how a deliberate focus on interoperable data formats and the introduction of an abstraction layer for connecting to other packages allows Move to deliver a single consistent environment for geological modelling. Move utilises the Geospatial Data Abstraction Library (GDAL) (Open Source Geospatial Foundation, 2015) to provide access to a raft of raster and vector data formats familiar to users of Geographic Information Systems (GIS) packages. The Move link for GST project demonstrates how we can apply our model of an “abstract connection” to reuse code when linking to any external system (see figure 2).

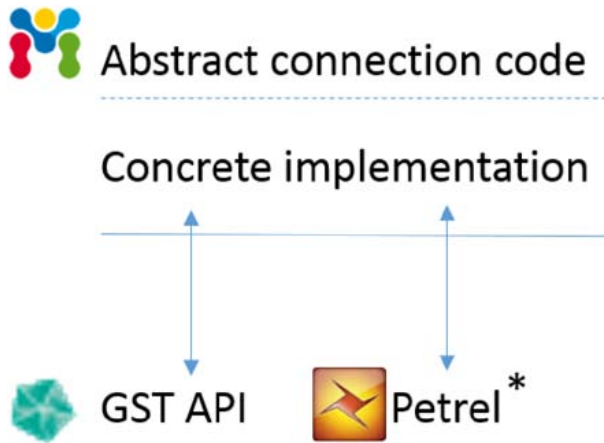


Figure 2 – Abstract connection from Move.  
\* Mark of Schlumberger

This approach allows rapid development of linkages to other systems to be added to our existing suite of connections (including GST and Petrel). The next phase of development is planned to involve connection to a traditional 2D GIS data store such as ESRI's ArcGIS Server: this would deliver a coherent modelling environment to users with both 2D and 3D geological data requirements.

#### ACADEMIC COLLABORATION

Our Academic Software Initiative (ASI) provides universities with our structural modelling and analysis software, Move, free of charge for teaching and non-commercial research. We encourage collaboration and data sharing amongst our academic and survey partners.



Figure 3 – Single Move model composed from GIS raster, outcrop vector, and GST database sources

#### ACKNOWLEDGEMENTS

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# FROM EXTERNAL SOURCES TO EXTERNAL USERS: A REVIEW OF GEOLOGICAL MODELING DEVELOPMENT WITHIN NATIONAL GEOLOGICAL SURVEYS

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KEY WORDS: 3D Modeling, Visualisation  
Discretization, Decision-making

## INTRODUCTION

Beginning in the late 1980's, a series of sophisticated three-dimensional modeling technologies – defined as Geomodeling Systems – have been developed to address the need for a precise definition of subsurface conditions (Turner, 1991). Geological modeling requires the extension of traditional GIS methods (Turner, 2000; 2006) and the modeling process remains technically challenging. Geologists have always recognized the need to view the world as multidimensional. The requirements for subsurface characterisation and modelling may be defined as follows: “The industry requires a system for interactive creation of spatial and spatio-temporal models of the physical nature of portions of the Earth's crust. i.e., the capability to effectively *model & visualise: the geometry* of rock- and time-stratigraphic units, the spatial and temporal *relationships* between geo-objects, the variation in internal *composition* of geo-objects, the *displacements* or distortions by tectonic forces, and the *fluid flow* through rock units.” (Kelk, 1991). Interpolation between widely spaced field observations requires geological knowledge to successfully replicate actual geological environments. Iterative methods involving assessments and progressive refinements may add considerable time and cost to the creation of subsurface models, unless the workflow is carefully defined (Turner, 2006).

Unlike the older resource-industry-based user-community, many of today's potential users of geomodels and visualizations cannot readily interpret basic geoscience data or evaluate the merits of alternative interpretations. They may be unable to distinguish between theories and facts. In short, these new users clearly desire “solutions, not data” and “information in understandable form” (Turner, 2006)

## THE GEOLOGICAL MODELING PROCESS

Figure 1 illustrates the steps in a typical geological modeling process. Raw data collected from various sources can be considered as two types – spatial data and properties data. The spatial data are used to create a 3-D geometry model, shown on the left-hand side of Figure 1.

Geometry modeling involves two steps: first the development of a suitable geometric representation of the fundamental geological “framework,” and second the subdivision, or “discretization” of this framework to provide control for the analytical computations within the numerical models used in the predictive modeling. The horizontal arrow linking the discretization and analytical modeling operations in Figure 1 defines this linkage.

Implicit in this overview is the feedback in each step of the process in which downstream steps may feedback and influence upstream actions as the process is iteratively undertaken.

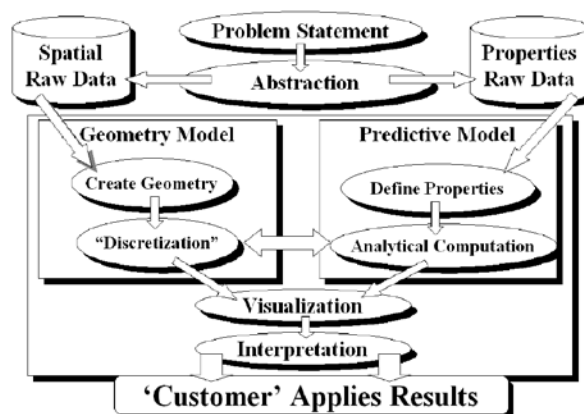


Figure 1 – Overview of the Geological Modeling Process.

The development of a geometrically accurate representation of the geological framework, suitable for visualization, serves to define and control the spatial distribution and propagation of rock-properties required by modeling. Framework definition is accomplished by applying a variety of data types, including (a) borehole and isolated sample data, (b) surfaces (triangle, quadrilateral, NURB), (c) 2-D grids and meshes, and (d) a variety of iso-volumetric models created from multiple surfaces, cross-sections, and grids and meshes.

The primary objective of subsurface geometry modeling is to provide geometric controls and property distributions for some type of numerical modeling, and the purpose of this analytical modeling is prediction. The right-hand side of Figure 1 identifies this predictive modeling step. Prediction has an extrapolative rather than interpretive character; thus it involves risk and uncertainty. Prediction leads to decision-making. Predicted results often require supporting visualizations and interpretations that can be presented to and used by the “customer” of the modeling results. Both the geometry and predictive models are shown in Figure 1 as passing through visualization and interpretation to delivery to the “customer.”

### GEOLOGICAL MODELING WITHIN INFORMATION MANAGEMENT SYSTEMS

Efficient delivery of modeling results, as well as effective modeling, depends on the use of sophisticated information management. Figure 2 illustrates the four basic components of an integrated geological data modeling and information management system. The central technical core contains the technical tools supporting geological framework model development and numerical, predictive simulation modeling. The technical core is surrounded by four supporting components. The “infrastructure” component is required to keep the system operating smoothly. The workflow management component provides tools to access the technical core, including user interfaces, and also links to the risk assessment and decision support component that contains software tools for risk assessment and decision making. The dissemination component manages the production and distribution of results generated by the system.

These concepts and requirements were first used to meet the requirements of the U.S. Geological Survey Death Valley ground water project (Rosenbaum & Turner, 2003; Turner & Gable, 2007). Currently several national geological survey organizations are employing these concepts to manage their geomodeling and data repository responsibilities.

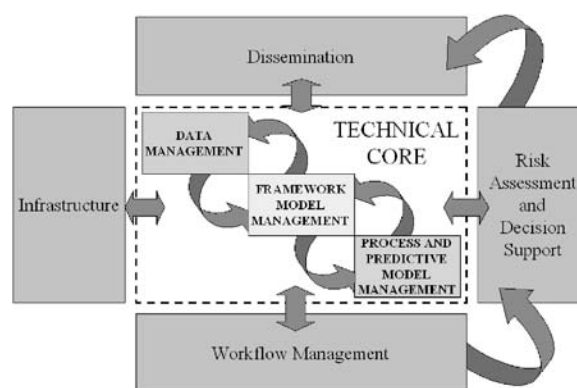


Figure 2 – Integrated geological data and information management.

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## A voxel model for mineral resources: Loess deposits in Flanders (Belgium)

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**KEY WORDS:** Loess, Quaternary, 3D, voxel model, parameter model, mineral resources, mineral resource policy, land use planning, extraction.

### INTRODUCTION

For a sustainable application and management of the Flemish subsurface, knowledge about geometry and geology is of great importance. As a response the Flemish Government ordered VITO to set up a 3D geological layer model (G3Dv2, Matthijs et al., 2013) of the subsurface of Flanders. In relation to mineral resources in Flanders VITO also started to build 3D voxel models in 2013. The first voxel model has been finished in February 2015 and represents the Quaternary loess deposits in Flanders. These deposits are still of great importance for the ceramic industry in Belgium.

The loess deposits in Flanders are part of a late Pleistocene loess belt that covers older most of other Quaternary and Tertiary sediments in the southern part of the Flanders Region and Brussels-Capital Region. The location of these deposits is illustrated in figure 1.

### METHODOLOGY

VITO has developed a new methodology for the voxel model based on software programs Voxler, Surfer, ArcGIS and AutoCAD.

The boundaries of the model are extracted from the G3Dv2 model and the Quaternary Geological map of Flanders (Bogemans F., 2005).

The voxel model is based on a dataset of more than 8,000 usable boreholes available at the online subsurface database of Flanders, <https://dov.vlaanderen.be>. All the selected borehole intervals were, prior to interpolation, encoded and classified in one of the following 9 lithological classes: anthropogenic material, organic matter, clay, loess, sandy loess, loamy sand, sand and gravel.

The interpolation of the model is based on Kriging and IDW. Consequently the 'body' of the loess model contains voxels (25x25x0.5m) that represent a modelled lithology on a regular grid in three-dimensional space.

### A VOXEL MODEL OPEN TO EXTERNAL USERS: THE 'MINERAL RESOURCE EXPLORER'

For presenting the voxel model to the interest groups of external users the Flemish government has set up a special online viewer called the 'mineral resource explorer' (illustrated in figure 2). This explorer allows users to view and query the different mineral resources present at any possible location in Flanders. On the one hand land use planners can estimate the total amount of useful primary mineral resources before developing a parcel. On the other hand, it's a tool for the mineral extraction industry to plan mineral extraction before even executing drillings.

From a scale of 1/50.000 it is possible to determine the extractable mineral resources based on certain preconditions such as: maximum depth and minimum thickness of the mineral resource, maximum thickness cover and maximum thickness of other lithologies.

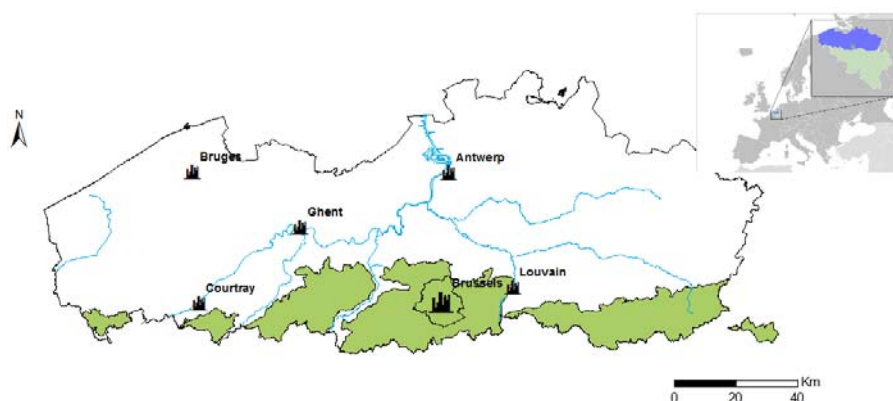


Figure 1 – Location (green) of loess deposits in the southern part of Flanders, Belgium.



Figure 2 –extractable loess deposits shown in the online mineral resource explorer

Furthermore specific interactions make it possible to see the voxel model on an XY-location, a cross section and even to calculate the volumes of mineral resources of a polygon, such as a future extraction area (illustrated in figure 3).

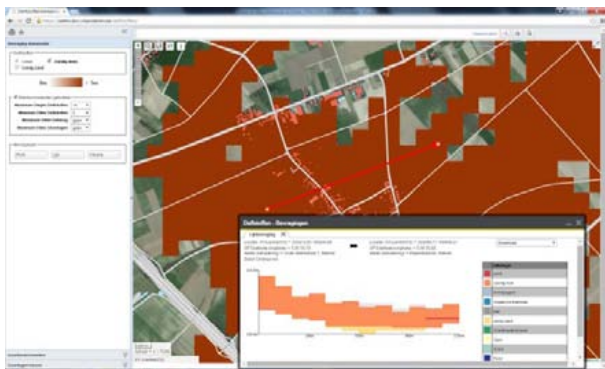


Figure 3 – a cross section and volume calculation of loess deposits shown in the online 'mineral resource explorer'.

The first voxel model of Quaternary loess deposits in Flanders has been uploaded in the 'mineral resource explorer', available at DOV.

Tests are running to incorporate the loess model, together with the already available G3Dv2, in the 3D SubsurfaceViewer® available at the DOV-website. This viewer specializes in a combined 2D-, profile- and 3D-View and allows to get an insight in the geological and geographical relation of these two models.

In the future it will also be possible to upload other voxel models such as fine sand, construction sand, gravel and clay. It will be possible to elaborate the model with other parameters for example grain size, chemical and mineral constitution.

## CONCLUSIONS

It's an interesting case of developing a voxel model and making it accessible to external users. As a result it allows users to view 3D data, to do calculations and to combine it with other models and geographical information. A project such as this also stimulates collaboration and gives more insight into the needs and possibilities of a voxel model to all the parties concerned.

## ACKNOWLEDGEMENTS

We would like to express our gratitude to all the project members of VITO and the Flemish government. We are thankful for their guidance, constructive criticism and advice. We are also grateful to them for sharing their illuminating views on a number of issues related to the project.

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## H3O – a (hydro)geological model that opens the frontier

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**KEY WORDS:** 3D-modelling, Belgium, correlation, cross-border, Flemish region, geology, hydrogeology, lithostratigraphy, the Netherlands, the Roer Valley Graben.

### INTRODUCTION

The Roer Valley Graben, an active rift basin in western Europe, is of great importance for drinking water supply in both the Netherlands and Flanders. Although the occurrence and behaviour of groundwater are not restricted to national borders, Flemish and Dutch groundwater managers were faced with inconsistencies between Flemish and Dutch subsurface information, which led to uncertainty in the understanding of the groundwater system in the border region.

Unambiguous (hydro)geological knowledge and information are essential for sustainable management and use of not only groundwater resources but of the entire subsurface.

Therefore parties in the Netherlands (Province of Limburg and Province of North Brabant) and Flanders (Environment, Nature and Energy Department of the Flemish Government and the Flemish Environment Agency) expressed their interest to attune the (hydro)geological models of the Roer Valley Graben.

Accordingly the H3O-project was initiated, which ran from March 2012 to June 2014 and was carried out by TNO Geological Survey of the Netherlands and the Flemish organisation VITO in collaboration with the Geological Survey of Belgium.

### H3O – ROER VALLEY GRABEN

The aim of the H3O-project was to make a cross-border, up-to-date, three dimensional geological and hydrogeological model of the Roer Valley Graben, which covers the southeastern part of the Netherlands and the northeastern part of Flanders. For this purpose, existing (hydro)geological knowledge (fault traces, nomenclatures, seismic and well(-log)

interpretations, existing (hydro)geological maps, etc.) were gathered and reinterpreted into one consistent dataset that served as input for the 3D modelling process.

The stepwise execution of the H3O-project consisted of:

- Data inventory and collection.
- Correlating Dutch and Flemish (hydro)geological units.
- (Re)interpreting existing data based on the new correlations.
- Creating 3D subsurface models based on the new interpretations.



Figure 1 – Location map of the modelled H3O-area of the Roer Valley Graben.

The final results of the H3O-project were delivered on 13 June 2014. The main results and conclusions are:

- For the first time, consistent geological and hydrogeological models of the Cenozoic sedimentary successions in the study area of the Roer Valley Graben have been created across the Dutch-Flemish border.
- Faults in the Roer Valley Graben are consistently modelled (in 3D) across the Dutch-Flemish border.
- A correlation scheme is presented for all the Dutch and Flemish (hydro)geological units in the Roer Valley Graben.

The Dutch and Flemish areas of these cross-border models are now one continuous entity. As a result of the way in which the models have been constructed, the geological and hydrogeological models are also geometrically consistent with each other. The models can therefore be considered as the state-of-the-art reference models for the geological and hydrogeological structure of the area. Based on these models, joint cross-border subsurface management of the Roer Valley

Graben will now be possible. Furthermore, the correlations between the Dutch and Flemish subsurface units may serve as a guideline for future cross-border projects.

The H3O-model is made publicly available for external users in the online Subsurface Databases “DOV” of the Flemish government and “DINOloket” of the Geological Survey of the Netherlands.

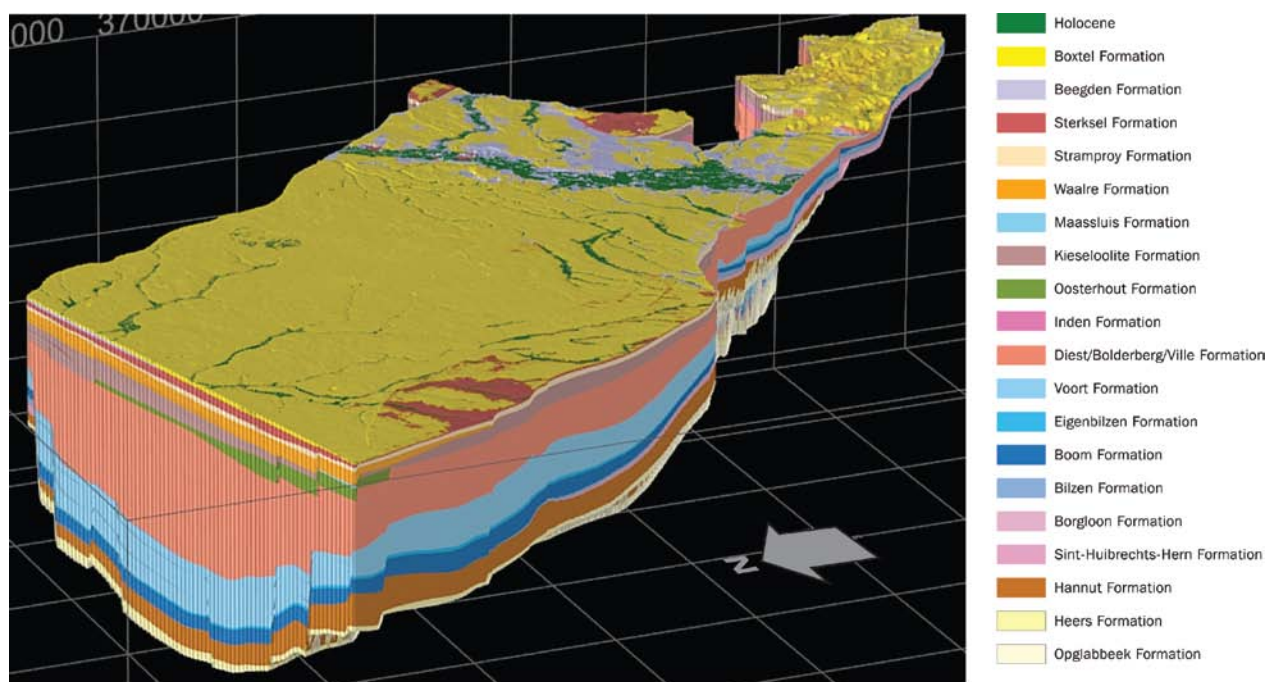


Figure 2 – 3D-model of the Roer Valley Graben in Belgium and the Netherlands (SubsurfaceViewer®).

### H3O - FUTURE

From April 2015 to the end of 2017 the adjacent border region of the Kempen area of the Netherlands and Belgium (Flemish region) will be modelled based on the same methodology.

Furthermore plans are being made to apply this methodology in the south-eastern part of the Roer Valley Graben, in the border region of the Dutch Province of Limburg and North Rhine –Westphalia.

### ACKNOWLEDGEMENTS

We are grateful to the H3O-projectteam of TNO, VITO, Provinces of Limburg and North Brabant of the Netherlands, the Belgian Geological Survey, the Natural Resources Service of the Flemish government and the Flemish Environment Agency.

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- INSIGHT GmbH, developer of the 3D SubsurfaceViewer®. <http://www.subsurfaceviewer.com>

## Communicating 3D Geological Models – Innovative techniques of visualization

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**KEY WORDS:** *3D geological models, innovative visualization techniques*

### Introduction

The development of three-dimensional geological models is a main objective of the Working Group of Hydrogeology and Environmental Geology at Martin Luther University Halle-Wittenberg. During the last years different geological models have been developed and as a result of the increasing complexity of the models and the modeling techniques, new questions regarding the visualization, the presentation and the communication of the technical and scientific content of the models arose. It has to be mentioned that the 3D-models under discussion have a high complexity and high resolution in vertical and horizontal scale. They are covering the entire subsurface of the cities e.g. Halle and Magdeburg up to 200 km<sup>2</sup>. The challenge in solving these questions was to find methods which would be also suitable for people beyond the geoscientific community. This also includes common problems of nearly every digital presentation mode: the absence of a real visual 3D perception and the ability to interact physically with the model beyond the computer based presentation.

### Methods

The presentation of the geological models should be possible without any additional digital and / or electronic media. As a result, the following innovative visualization techniques are introduced:

- a) Lenticular 2-phases flip, which combines image information of e.g. aerial photograph and 3D-geological subsurface modeled section. These lenses filter the image information, depending on the viewing angle. The interactive approach in the internet was introduced as "3D Geo-stripping" in 2012 ([www.3d-geology.de](http://www.3d-geology.de)).
- b) True color hologram (i-Lumogram images) is a new technique of GEOLIA Ltd. (Vilnius) which allows a colored presentation of the complex 3D modeled structural information and gives a very impressive 3D-view up to 75 % of print width focusing depth in back of the media.

However to create lenticular images or a hologram, a lot of single precisely rendered images is necessary. This can be a very challenging task, depending on the complexity and the size of the model (number of polygons) since the common rendering software is designed for low-poly models.

- c) Glass laser engraving models – Here the entire information of the 3D geological model are transferred by red or green lasers into a polished crystal glass block of optical (lens) quality. Technical reasons of the laser machine limit the depth of about 12 cm thickness. The recently used glass blocks have a format of app. 27 x 30 x 12 cm and 25 kg. The largest one – the mining infrastructure of Staßfurt - has a size of 27 x 60 x 12 cm and 52 kg! This presentation technique allows a very detailed and fascinating insight view of the entire model area.

The development of a glass laser engraving models of course necessitates an existing 3D geological model (surface or boundary representations). However it makes no difference which modelling software was used to create the geological model. But depending on tools and software, the model data needs to be adapted for this purpose. This includes a conversion to applicable data formats as well as a treatment depending on the presentation objective. The data preparation and manipulation of the strata may include clipping, exaggeration or changing the elevation for an exploded-view to visualize different aspects. It is also possible to include mining infrastructure to show the relationship between the geology and the mine structure. The working group created several glass laser engravings in cooperation with STARGLAS GmbH, Bünde, Germany based on 3D geological models developed in collaboration with the "Bundesanstalt für Geowissenschaften und Rohstoffe" (BGR) and the "Landesamt für Geologie und Bergbau, Sachsen-Anhalt" (LAGB).

However to create lenticular images or a hologram, a lot of single precisely rendered images is necessary. This can be a very challenging task, depending on the complexity and

the size of the model (number of polygons) since the common rendering software is designed for low-poly models. The following sections give a closer look on some of the models.

### Structural model of Halle (Saale) City

This geological model shows the fault system and the distribution of the consolidated rocks in the deeper underground of the city of Halle (Saale) in Saxony-Anhalt, Germany. This model was created with 3D MOVE in cooperation with the LAGB based on seismic and drilling data down to a depth of about 1000 m.

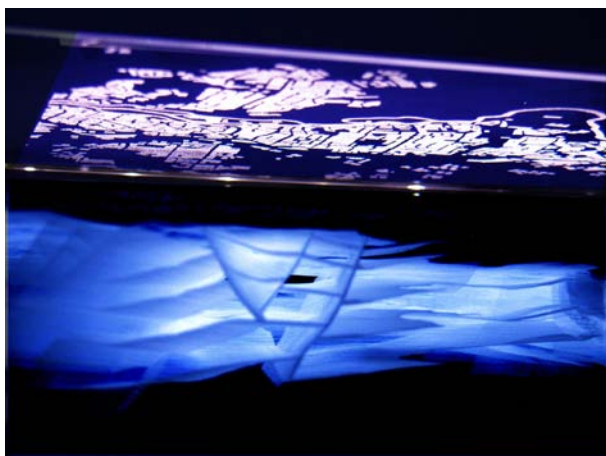


Figure 1 – Glass laser engraving geological model Halle (Saale) City.

Fig. 1 shows the resulting glass engraving (26 x 30 x 12 cm). The top of the glass cuboid depicts a simplified map of the urban area of the city, which allows a better orientation.

### Geological model of Magdeburg City

This model covers the urban region of the city of Magdeburg (Saxony-Anhalt, Germany) with a total area of about 195 km<sup>2</sup>. It shows the geological basement with its typical fault system as well as the unconsolidated rocks of tertiary and quaternary age.

The resulting glass laser engraving depicts the geology with 52 million laser points (Fig. 2). For visualisation purposes the lower part of the models consist of consolidated sediments are effected strongly by a extended fault system and was presented without any exaggeration, while the above followed highly differentiated unconsolidated rocks of tertiary and quaternary age have an exaggeration to 15-fold and are presented in a “flying carped” mode.

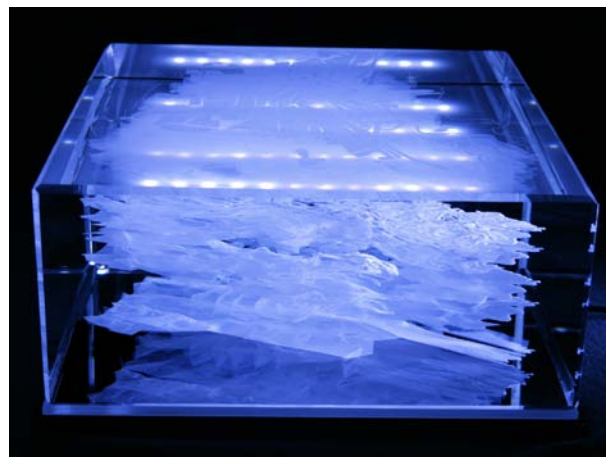


Figure 2 – Geological model Magdeburg City.

### Salt mining infrastructure, Staßfurt City

As already described it is also possible to engrave the complex structure of a mining infrastructure of a former salt mining complex. This project was realized in cooperation with the BGR, Hannover. The model shows the up fold base of the potassium salt stratum "Staßfurt" (Zechstein) and the detailed infrastructure of the different mining galleries, tunnels and headways. The model covers an area of app. 11 x 2.5 km and is assumed as the largest geological model of a glass laser engraved block.

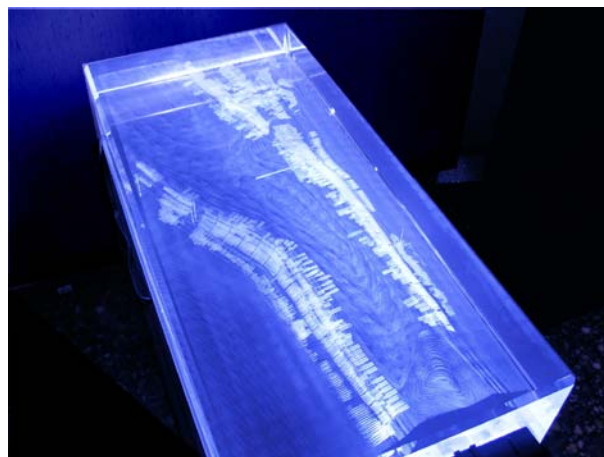


Figure 3 – Mining infrastructure and geology

Fig. 3 shows the glass engraving (60 x 27 x 12 cm) of the salt mining infrastructure located in Staßfurt (Saxony-Anhalt, Germany).

### Further information:

Home 3D-Geology  
[www.3d-geology.de/](http://www.3d-geology.de/)

Scientific exhibition  
[www.3d-geology.de/ausstellung/](http://www.3d-geology.de/ausstellung/)  
[www.3d-geology.de/3D\\_geostripping/](http://www.3d-geology.de/3D_geostripping/)

## **GEOLOGICAL 3D MODELLING - POSTERS**





## OUTREACH POTENTIAL OF THE INTERACTION BETWEEN 3D MODEL AND GEOLOGICAL MAPPING ON A WEB PLATFORM

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**KEY WORDS:** *multidisciplinarity, multiscale, geoheritage, e-learning, dissemination, 3D visualization.*

### INTRODUCTION

In order to better understand the geological, morphological and environmental importance of an area, it is essential to choose the right tool to release this kind of scientific information (Martin et al. 2014). A common platform of database with a simple user interface for many research groups could be a tool to allow the dissemination of information, previously processed by specialists using the GIS, to different types of users.

Our proposal is to use a 3D model for disseminate geo-scientific knowledge and reaching the most different kind of users: primary and high schools students, sightseers, amateurs, etc. "EASY TO REACH" is the goal of the 3D tool: using it, you can even have a helicopter view or you can observe something from unreachable viewpoints, in other words, it allows a virtual "geowatching" (Garofano 2014). Since the tool allows you to identify, recognize and emphasize a geomorphosite, the 3D exploration becomes a powerful support in visiting "hard to reach" sites and to choose the best viewpoints to observe the sites of interest and therefore to plan how to reach them.

### 3D SCENARIO

The platform 3D consists of two portions: the 3D-Scenario (Digital Terrain Model) including the database structure, downloaded free on your PC, and the database contents that resides on an external server. It must be downloaded and installed both the software for 3D navigation and the 3D-Scenario ([www.openalp3d.it](http://www.openalp3d.it)) containing: vector elements (the recorded and geo-referred elements), raster maps (maps, digital orthorectified images, etc.), as well as links to online maps (eg Googlemaps, National Cartographic Portal, etc.).

It is an efficient tool for in-depth analysis of landform and a good facility for educational and research purposes on geomorphosites.

The localization of each site, together with the more common descriptions, classifications and pictures, enables the user to understand in detail

relevant morphological sites and to identify their elements displayed on a 3D-Scenario, either when laid over orthophotos or geological, geomorphologic, or other thematic maps (Fig.1). Different types of users will be able to appreciate thoroughly the scientific, educational and scenic geomorphosites peculiarities the key elements to understand the geological, geomorphological evolution of the territory.

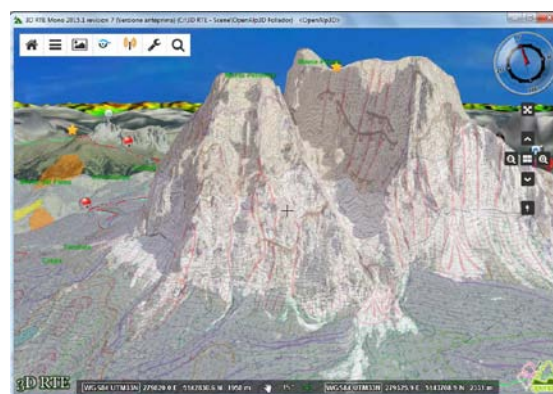


Figure 1 – OPENALP3D: geomorphologic map overlapping a 3D scenario in Dolomites

The architecture of the system ensures dynamic contents through an upgrade process and the platform becomes the collector of the scientific contributions relating to the territory. The external server provides HTML pages containing information and documents, but also acts as a collector for new items: those who are authorized to enter data, upload to server vector elements and create html pages containing related information, images and files to download (gpx, kml, pdf, etc.). Every time the user opens the scene with an internet connection, automatically downloads these updates.

WEB users, with this dynamic 3D tool, can to explore large areas (Fig. 2) of the territory through a digital terrain model with a detail fit for purpose: with a simple click you must be able to prepare for your hikes, knowing in advance the territory, bike riding first at home virtually in 3D, discover the territory, step after step through the paths prepared for you! Each route must be accompanied by a technical card with altitude, photos, descriptions, PDF maps and .gpx files that can be downloaded. These utilities could be a

starting point to stimulate and develop a sustainable geo-tourism in upland, often

depopulated because of lack of expectations.

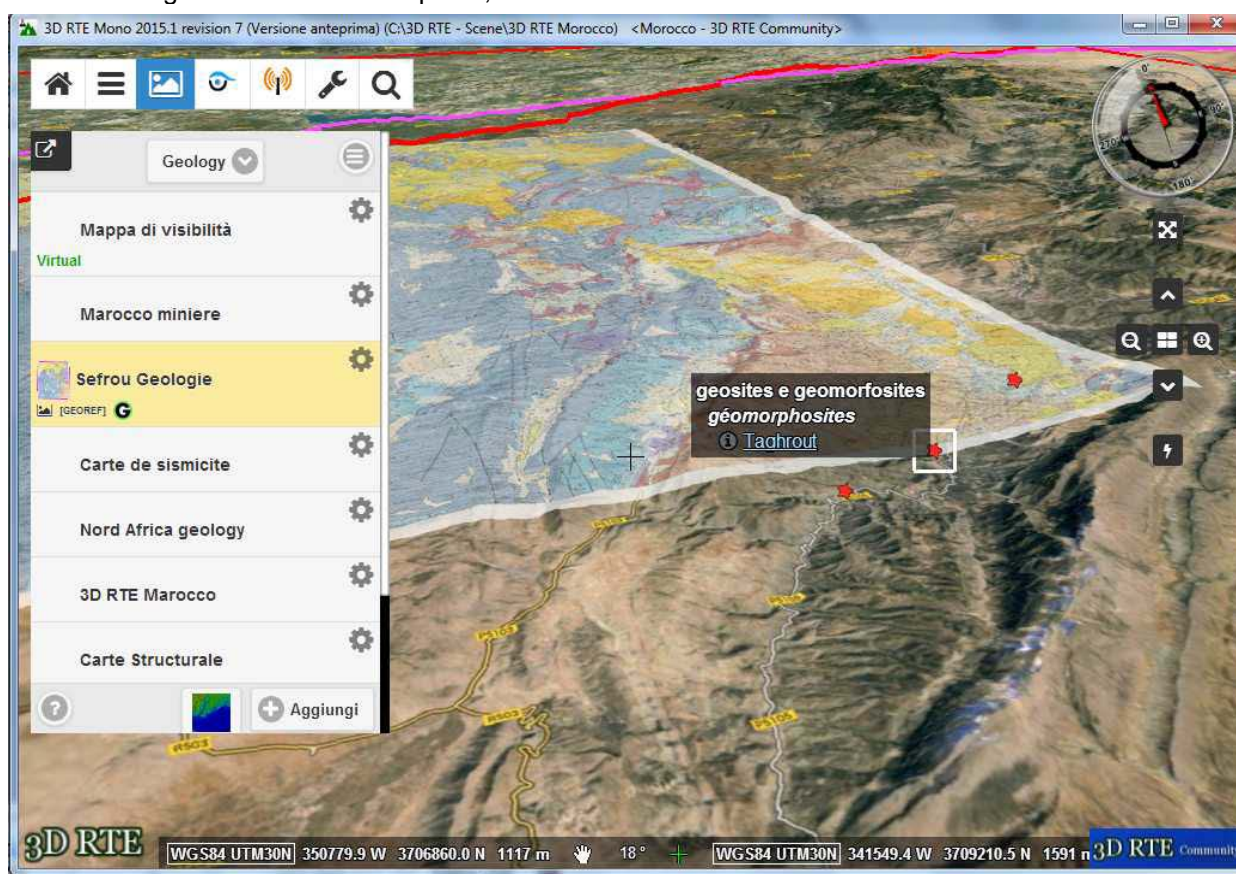


Figure 2 – MAROC3D: example of visualisation 3D of geological map together with geosites locations.

## FINAL REMARKS

It is a multidisciplinary platform that provides dynamic management of information and allows the creation of dynamic descriptions and enables the creation of movies, it could be the starting point for the creation of "places of collective identity", dissemination of geosciences, promotion and protection of the territory.

The educational value of this platform was tested at the Mining Institute Follador (Agordo) and it was considered as a useful tool to support teaching in geology and geomorphology through the use of a computerized classroom: during lessons, students can navigate on a 3D model (5x5m cell), choose different maps (topographic, geological, geomorphological, etc.), recognizing the geological sites and geomorphosites and delimit them by drawing points, lines and areas to improve understanding.

For development of sustainable tourism and for territory promotion, the geomorphosites can be integrated and shown on the same 3D-Scenario together with all the most important territorial elements such as natural, cultural-historic heritage and all the tourist accommodation and facilities information.

## ACKNOWLEDGEMENTS

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## WORKFLOW FOR 3D GEOLOGICAL MODELLING IN CO<sub>2</sub> STORAGE ASSESSMENT

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**KEY WORDS:** CO<sub>2</sub> storage, ALGECO2, static model, dynamic model.

### INTRODUCTION

This work is part of the Plan for the Selection and Characterization of Favorable Areas and Structures for Geological CO<sub>2</sub> Storage in Spain, ALGECO2 (IGME 2010, 2014). The first phase of this plan yielded 103 favorable structures for geological CO<sub>2</sub> storage containing the storage-seal formation pair. In a second phase, onshore structures as well as some offshore continental shelf areas close to mining regions were studied according to the requirements set by the *Instituto para la Reestructuración de la Minería del Carbón y el Desarrollo Alternativo de las Comarcas Mineras* (IRMC)

The aim of this paper is to present a common methodology for the characterization and detailed modelization of 13 potentially favorable areas.

### INPUT INFORMATION

The input information comes from the compilation of data from the first phase of the ALGECO2 project with the exception of the offshore areas, in which case the data come from the IGME public information database.

The data used comes from: geological maps, seismic lines, deep boreholes, geological sections, gravimetry, magnetism and data from the previous structures defined in the first phase of the ALGECO2 project).

### DATA ACQUISITION AND PROCESSING

After reviewing the input information and taking into account the needs of the modeling tasks, we compiled for study new information from the Technical Hydrocarbon Registry. In order to complete the geological and geophysical information needed to build up a 3D model, field

surveys were carried out, mainly gravity and rock sample collection for petrophysical characterization

In those cases where subsurface data is non-existent or incomplete we made balanced cross-sections that were improved with 2.5D gravimetric and magnetic modeling maintaining the restitution criteria.

When available, we used the data from the well-logging surveys to adjust the depths of the horizons and to obtain petrophysical data such as density, porosity and permeability as well as storage conditions at depth like geothermal gradient, temperature and salinity. These data were used for the dynamic simulation models.

### 3D STATIC MODEL CONSTRUCTION

Static models were built from the interpretation of seismic profiles and/or balanced cross-sections (Figure 1) using Geomodeler and gOcad.

These data, together with surface geology, petrophysical data and well information allow building horizon and fault surfaces. The surface horizons include the tops of the storage formations as well as other surfaces that allow the model to include the regional geologic context. Faults were treated in the same way as surface horizons.

These surfaces, defined by the stratigraphic sequence, delimit the lithological volumes from which storage rock volume can be obtained.

The purpose of the static model is multiple. On the one hand, it is useful to recreate the three-dimensional geometry of the geological structure in order to verify its validity as a storage site (deepest closed contour estimation, fault influence). On the other hand, the static model allows the calculation of the storage rock volume which together with the petrophysical parameters and physical conditions at depth is used to estimate the storage capacity. Finally, the surfaces that delimit the structure are used to reproduce the

storage rock boundary conditions in the dynamic model.

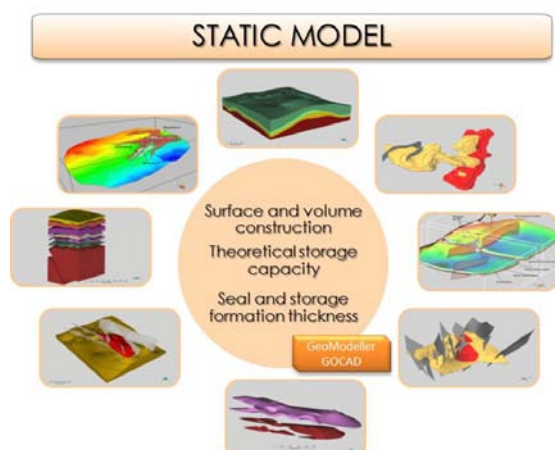


Figure 1 – Static 3D geological models.

## DYNAMIC MODEL

The dynamic model is the final step in the work-flow set out in ALGECO2 project (Figure 2) that complies with the current legislation requirements in Spain (Law 40/2010 of December 29 on geological storage of carbon dioxide) in relation to the criteria for characterization and assessment of geological storage and its surrounding area.

The simulator used for this purpose is TOUGH2 under the PetraSim user interface. The TOUGH2 code has been widely used in this specialized field because of its ability to characterize the fluid and gas phase properties within a wide range of temperature and pressure values ( $10^{\circ}\text{C} \leq T \leq 110^{\circ}\text{C}$ ;  $P \leq 600$  bar).

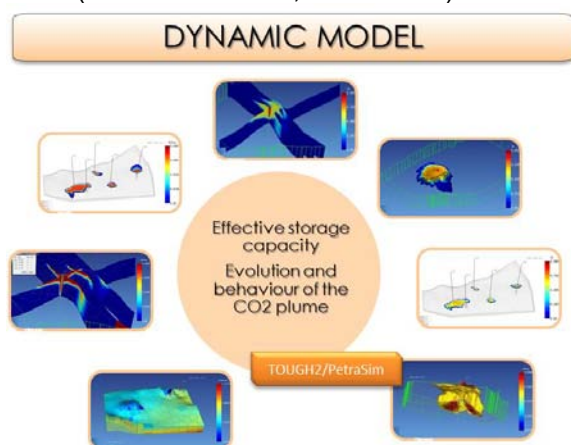


Figure 2 – Dynamic geological 3D models.

The storage and seal layers obtained in the static models are imported into the dynamic simulation code and assigned petrophysical and hydrogeological properties. These properties have been determined through laboratory testing and rock samples analysis or were obtained from deep hydrocarbon boreholes and their hydraulic tests.

The dynamic models at reservoir structure scale are run for the injection and post-injection phase, and the results show the evolution of the pressure gradient as a function of the injection flow rates and total simulation time, spatial extent and  $\text{CO}_2$  plume migration in the different phases. The model simultaneously allows the quantification of the  $\text{CO}_2$  ratio captured by every trapping process. Given the high degree of uncertainty in the input parameters, each model considers several possible scenarios in which the impact of change in porosity or permeability is studied in relation with the model results and the selected boundary conditions.

The dynamic model provides a more realistic estimate of the effective storage capacity as it takes into consideration all the petrophysical characteristics and physicochemical processes taking place in the storage site.

## RESULTS AND CONCLUSIONS

We have developed a common working methodology for the construction of 3D static and dynamic models of favorable  $\text{CO}_2$  storage structures, according to the Spanish Law 40/2010 on geological storage of carbon dioxide.

We have selected 13 structures of the 103 initially identified potential areas according to the established criteria from the first phase of the ALGECO2 project.

To determine the viability of these structures as  $\text{CO}_2$  storage sites and their storage capacity, the corresponding 13 static models were constructed.

Dynamic simulations have been conducted in three of the selected structures in order to validate the storage capacity and as a tool for predicting  $\text{CO}_2$  plume behavior considering different physical conditions during injection and in the long-term.

## ACKNOWLEDGEMENTS

Financial support for this study was received from the Spanish administration through the *Instituto para la Reestructuración de la Minería del Carbón y el Desarrollo Alternativo de las Comarcas Mineras* (IRMC).

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## 3D FIELD MODEL OF THE POST-VARISCAN SEDIMENTARY SUCCESSION AT THE NOGUERES (PYRENEES)

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**KEY WORDS:** Pyrenees, 3D, Nogueres Zone, Triassic, Paleozoic.

### INTRODUCTION

The 3D modeling of relevant outcrops allows a better understanding of geology and enhances outcrop-based learning. For this study (Figure 1) we selected outcrops of the Southern Pyrenees (Lleida province) that belong to the sedimentary infill of the post Variscian extensional basins found between Noguera Pallaresa and Noguera Ribagorçana rivers.

### GEOLOGICAL FRAME

The Erill Castell half-graben is located at the Southern limit of the Axial Zone (variscian basement) and was formed during the Upper Carboniferous extension, together with other basins such as Estac, Gramós, Cadí and Castellar de n'Hug-Camprodon. These basins were filled by autochthonous Stefano-Permian volcanics and detrital deposits resulting from the erosion of the Variscian reliefs. These syn-extension deposits were overlapped by Late Permian to Early Triassic (Buntsandstein) continental sediments. During the Alpine orogeny, which took place in the Pyrenees from Upper Cretaceous to Eocene, the Erill Castell half-graben was inverted (Saura & Teixell 2006) along its major border fault (Erta thrust). This inversion resulted in the extrusion of bedding-parallel back-thrusts and in the steep southwards tilting of the basin infill.

The stratigraphic succession of the Erill Castell basin allows us to carry a detailed outcrop study and a further 3D modeling of the major unconformity between the Paleozoic and the Triassic deposits. This 3D model permits us to characterize the main structural and stratigraphic analogies for hydrocarbon traps, which can be compared with several examples worldwide. In the early extension, a volcanic episode took place (Martí, J. 1981 and Gisbert, 1984) with the deposition of andesitic lava and pyroclastic levels (Erill Castell Fm). After this volcanic episode, a strong erosion that affected the variscian reliefs led to the sedimentation of detrital sediments such mudstones and sandstones interbedded with coals, (Malpàs Fm). Afterwards, a thick red-bed succession was deposited during the Permian and Triassic (Peranera Fm. and Buntsandstein facies, respectively). The Peranera formation includes a detrital and volcanoclastic succession (Lower Red Unit) and a mudstone dominated detrital succession (Upper Red Unit). The contact between the Peranera Fm (dipping 75 degrees) and The Buntsandstein facies (dipping 65 degrees) is both an erosive and an angular unconformity. On top of the Buntsandstein unit, the

Muschelkalk and Keuper facies are found. The contact between these latter surfaces can be used as the datum (flattening surface) for this study.

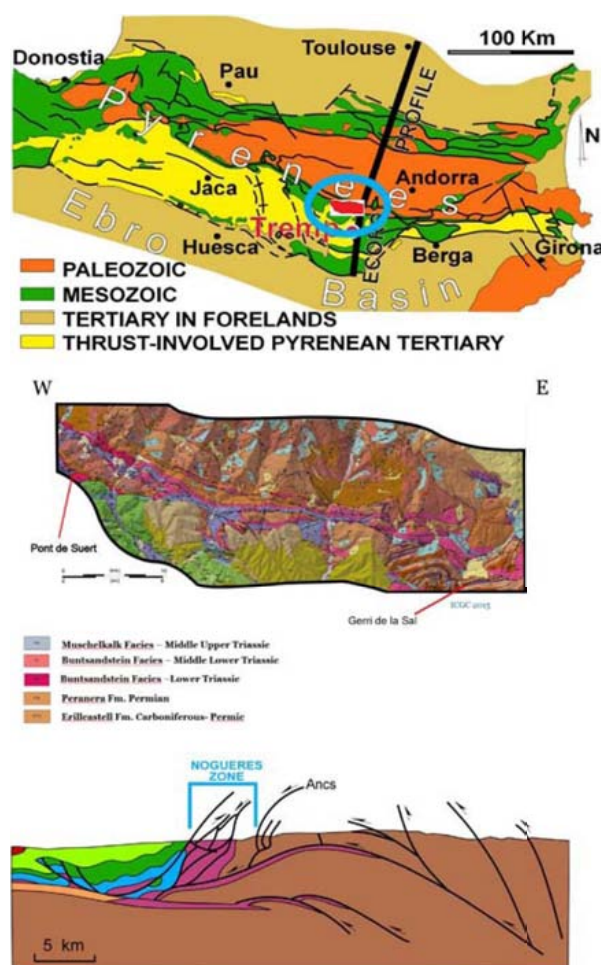


Figure 1 – Top: general geological location of the study area; Middle: Geology of the study area (ICGC 2007). Bottom: Nogueres cross-section by Muñoz (1992).

### THE 3D MODEL WORKFLOW

To build up the 3D model the first step was to digitalize the geological contacts. Global Mapper Software was used to load the contact coordinates (WGS 1984) and the Digital Elevation Model (DEM) that were later used by Petrel 3D Modeling Software. We combined this information with dip measurements, data acquired in the field and some cross sections of previous works (Saura and Teixell, 2006). The obtained information permits to create 3D surfaces. DEM,

orthophotos and different maps (geological and topographical) were used in order to achieve an accurate combination of all the elements.

By digitalizing cross sections contacts and dip measurements we had a preliminary idea about the orientation and the geometry of the modeled surface. In order to improve the reliability of the model, it was necessary to correctly divide surfaces in different dip domains. These dip domain divisions were initially done with Google Earth and were later easily modified with Petrel.

Once a surface was modeled, it was possible to edit its geometry and extension. This was first done by smoothing the surface in order to reduce local or general noise. Afterwards, we proceed to intersect surfaces with faults, onlaps, etc.

This is just the first step to obtain a 3D geological model on which, by further integrating sedimentary facies architecture and structural data in the next step of the study, potential analogs to hydrocarbon reservoirs will be constructed.

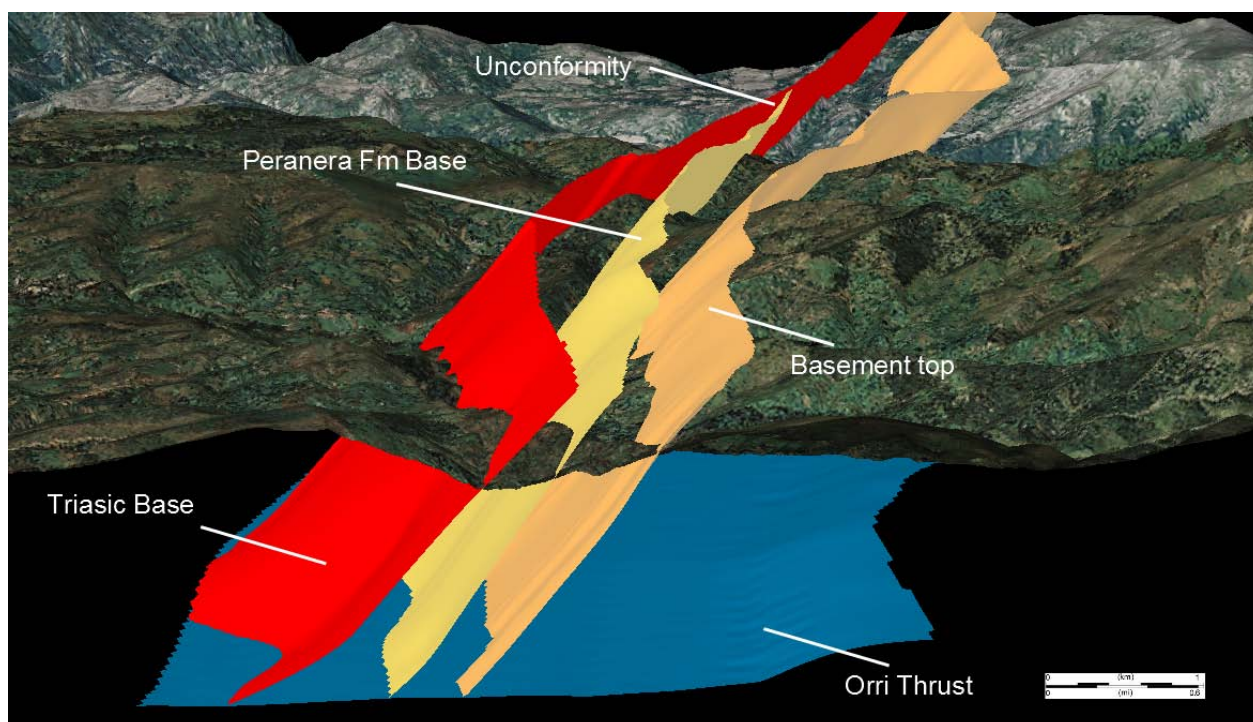


Figure 2 – Preliminary surfaces of a portion of the 3D model.

## ACKNOWLEDGEMENTS

Schlumberger Ltd kindly provided the academic licenses of the Petrel platform to develop this research.

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## 3D GEOLOGICAL MODEL FOR CO<sub>2</sub> STORAGE RESEARCH IN THE CENTRAL-EASTERN IBERIAN SYSTEM (MAESTRAZGO REGION, TERUEL-CASTELLÓN, SPAIN)

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**KEY WORDS:** 3D geological modelling,  
CO<sub>2</sub> storage, ALGECO2

### INTRODUCTION AND OBJETIVES

The IGME is developing a program of subsurface geology and CO<sub>2</sub> geological storage. This program has the overall aim to increase the knowledge of the structure and physical properties of Spanish subsurface and determine the capacity, spatial location and geometric characterization of susceptible geological formations that may be used as CO<sub>2</sub> storage sites (ALGECO2: IGME, 2010). The program received financing from the Instituto para la Reestructuración de la Minería del Carbón y el Desarrollo Alternativo de las Comarcas Mineras (IRMC), under the Ministerio de Industria, Turismo y Comercio, MITYC. In this context, several 3D geological models were made such as the Maestrazgo model shown here.

The main objectives of this study are:

- Improve and develop new methodologies for 3D geological modeling.
- Elaboration of 3D geometric geological models that increase the geological knowledge of CO<sub>2</sub> storage sites in the previously investigated areas of ALGECO2.
- Location and quantification of favorable zones for CO<sub>2</sub> storage. Determination of the geometry and thickness of storage and seal formations, storage depths, volumes, storage capacity, conditioning faults and detailed closure of the reservoirs.

### GEOLOGICAL SETTING

The modeled area is located in the central-eastern Iberian Chain (province of Teruel and Castellón) in the middle region of Maestrazgo matching the Maestrazgo-III zone from the ALGECO2 first phase, being almost centered in the town of Mirambell (Teruel).

The geology of the study area is characterized by horizontal and sub-horizontal materials together with soft fold structures.

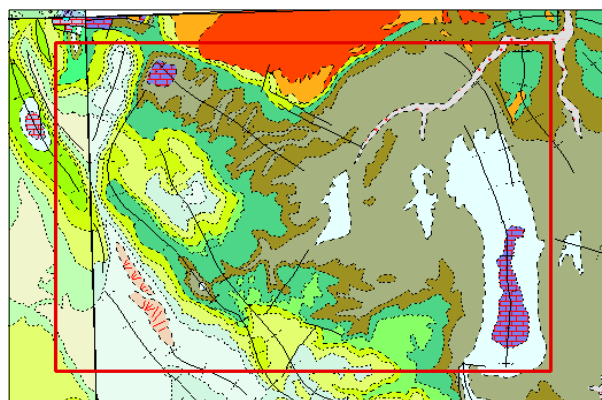


Figure 1: Study area limits (red) in the geological context of the IGME 1:200.000 sheets.

In the seismic studies (IGME, 2010), the observed faults affect both overburden materials and the Paleozoic basement, almost reaching the ground surface. Both fold and fault traces follow two general directions in this region: the Iberian Chain and the Catalan Coastal Range being NW-SE and NNE-SSW, respectively.

The modeled area is susceptible of constituting a geological CO<sub>2</sub> storage site in both the Buntsandstein sandstone-conglomerate and the Upper Muschelkalk dolomitic-limestone facies.

### METODOLOGY

For the elaboration 3D static geological model, geographic information systems such as ArcGis, seismic interpretation software (Geographix Discovery) and 3D modeling software (GoCad, Geomodeller) were used and a methodology, summarized in figure 2, was established. Regarding the data for obtaining of the 3D model, seismic information from the different horizons and from three deep hydrocarbon boreholes was used.

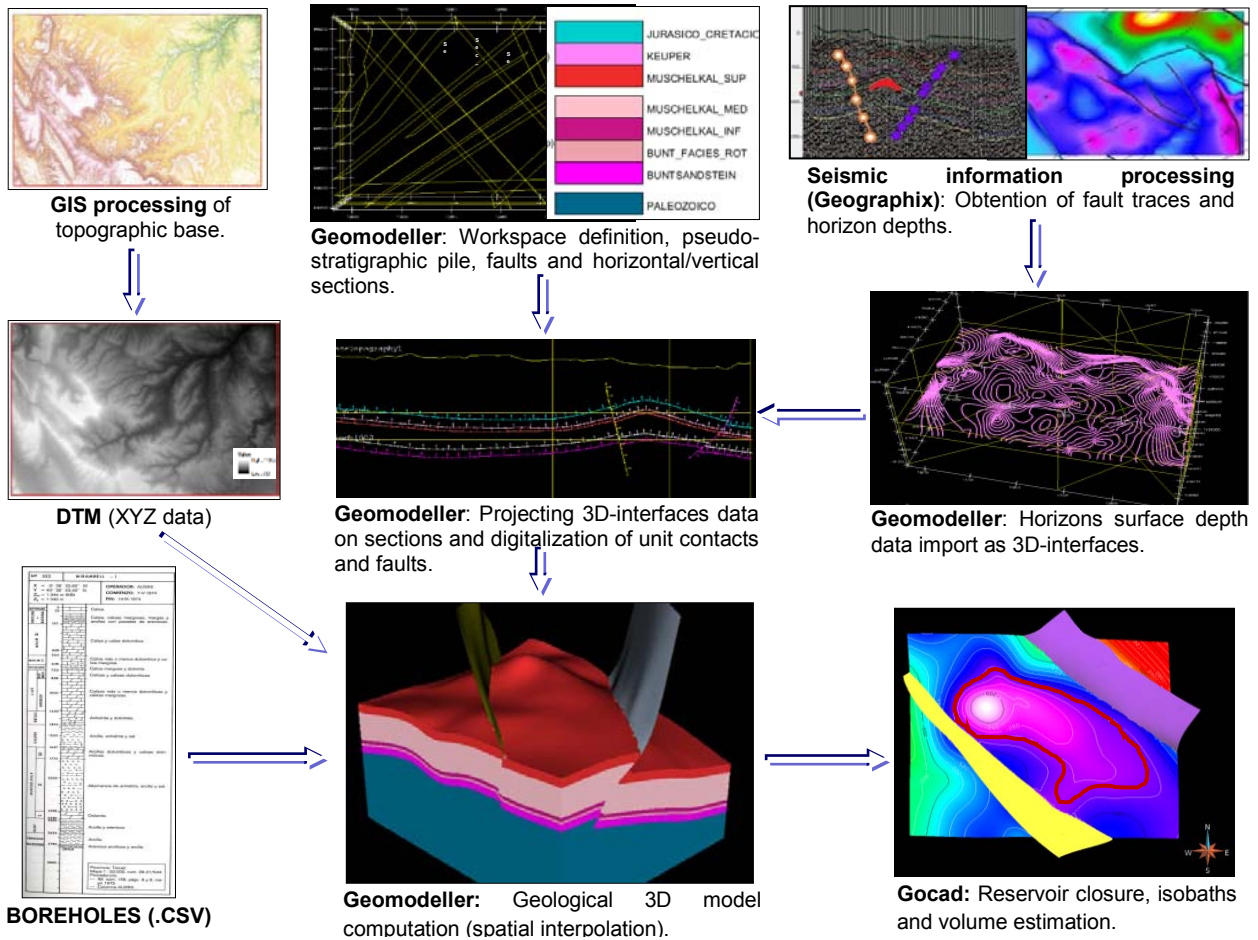


Figure 2: Summary methodology scheme and used data for the 3D geological models and CO<sub>2</sub> geological storage site determination in the studied zones.

**RESULTS**

A 3D geological model was obtained for the Maestrazgo-III. The model is geologically coherent permitting a correct spatial distribution and characterization of the different subsurface units and faults.

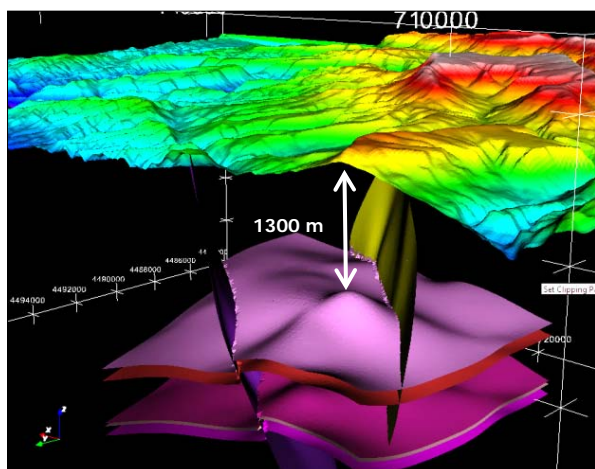


Figure 3: Detail of the 3D geological model including the DTM and tops of principal units in one favorable CO<sub>2</sub> storage site for Upper Muschelkalk (top in pink).

The model results discard the Bundsandstein facies as a favorable CO<sub>2</sub> storage unit in this zone of the Iberian Chain, due to its high depth, seal thinness and small size of potential zones. On the other hand, several favorable zones for CO<sub>2</sub> storage were identified in the Upper Muschelkalk, but with a limited extent and conditioned by the existence of faults that may reach the surface. One of these structures is shown in figure 3 with theoretical CO<sub>2</sub> storage capacity of approximately 3.81 MTn.

**ACKNOWLEDGEMENTS**

Financial support for this study was received from the Spanish administration through the *Instituto para la Reestructuración de la Minería del Carbón y el Desarrollo Alternativo de las Comarcas Mineras (IRMC)*.

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## A 3D DATABASE: A WAY TO PRESERVE DETAILED IMAGES OF THE TERRESTRIAL LATEST CRETACEOUS GEOLOGICAL HERITAGE IN TRANSYLVANIA (ROMANIA)

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**KEY WORDS:** latest Cretaceous, terrestrial deposits, vertebrates, geological heritage, 3D monitoring, Romania.

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### WAYS TO SET UP A 3D DATABASE

### INTRODUCTION

The latest Cretaceous (Maastrichtian) terrestrial formations from Transylvania are worldwide notorious for their vertebrate assemblages, including endemic small-sized (dwarf) dinosaurs, but also rare fish, turtles, crocodylians, birds, mammals etc. (GRIGORESCU, 2010, WEISHAMPEL et al., 2010).

This geological heritage is protected in the Haţeg basin (Southern Carpathians), where the "Dinosaurs' Geopark Haţeg Country" was outlined since 2004. Even before to be a geopark, inside this area several protected geological reserves were already coined, as: Sânpetru Valley or Tuştea. However, in spite of this status, in the last decade the evolution of the terrestrial latest Cretaceous exposures from Haţeg basin was unfortunate, either due to natural factors (e.g. rapid forestation by invasive plant species – mainly the black locust *Robinia pseudoaccacia*, or the exuberant development of certain algae which cover now whole sections of the Râul Mare or Bârbat rivers), or human ones (intervention with caterpillar on Tuştea dinosaurs' nesting site, followed by accidental removal of the fossil vertebrates bearing bed) (DUMBRAVĂ & SOLOMON, 2012)

Other areas exposing the same latest Cretaceous formations can be found elsewhere in Transylvania, as in Hunedoara, Alba, Cluj or Sălaj districts (CODREA et al., 2010, 2012a). A lot of these exposures are shearing the same inconvenient human interventions (e.g. in Sălaj, at Someş-Odorhei the works for a dam erased the red beds that contained dinosaur bones; in Alba district, the human induced pollution of the Sebeş River covers by refuse the outcrops).

In such a context, in order to let to the following generations of paleontologists and geologists images of the most representative such outcrops as they were nowadays, a 3D database

The three dimensional scanning of paleontological sites represents a new approach of tremendous capability which can only be tackled in the virtual realm. For 3D mapping and surface generation, two different techniques can be used.

LIDAR (Light Detection and Ranging) uses a laser rangefinder that generates a planar, fan shaped laser beam. The rapidly rotating beam coupled with a high speed camera simultaneously records the arrival of the reflections, recording hundreds of thousands of points in a user determined resolution. The major advantage of this method is the small amount of time required for data collection. The point cloud data thus generated can have surface accuracies on the order of a few centimeters and cover hundreds of square meters. Such devices can be mounted on ordinary vehicles for data recording while driving through an area of interest. The major disadvantage of the technology is it's high cost which can reach into the tens of thousands of dollars for top of the line systems. Such devices have been successfully implemented for a number of years at sites in North America for paleontological (BATES et al., 2006, 2008) and historical sites and in Egypt for mapping various tombs in the Valley of the Kings such as communal tomb KV35 (<http://www.thebanmappingproject.com/>)

Photogrammetry is a 3D scanning technique used for generating 3D surface maps from referenced photographs of a selected area. The area of interest is marked with a number of fixed points which are later used as references. The perspective shift from one photograph to another together with the relative shift in position of the reference points is interpreted and interpolated by specialized software in order to generate a point cloud used to render the surface. The great advantage of this technique is that it requires only a digital camera (the higher quality the better) and

a PC, the software used having freeware licenses. Also, a large user base exists online, therefore making troubleshooting much easier. The major disadvantage of his technique is the time required for data acquisition and its dependence on stable lighting conditions which could otherwise generate texture anomalies. This technique has already been used with much success (BATES et al., 2006; FALKINGHAM et al., 2014).

For the Maastrichtian terrestrial formations from Transylvania, we intend in the following decade to use the photogrammetry as tool for a 3D images database.

## OBJECTIVES OF MONITORING

The aim of our future monitoring will be all the exposures referring to the latest Cretaceous terrestrial deposits from Transylvania. Apart the Hațeg Basin (bearing the “classical” – i.e. some of them already noticed at the end of the 19<sup>th</sup> century – outcrops as: Vălioara, Densuș, Ciula Mare, Tuștea, Berthlot, Livezile, Totești, Nălaț-Vad, Sînpetru – Sibîșel Valley, Pui; CSIKI et al., 2010, with all related references), a lot of interest concern the regions outside Hațeg. Exactly, we intend to monitoring the Rusca Montană Basin (CODREA et al., 2012a), the southwestern side of the Transylvanian Basin, including the Maastrichtian localities: Teleac, Ciugud, Oarda de Jos, Lancrăm, Sebeș, Petreștii de Jos, Vurpăr, Șard (CODREA et al., 2010), but the northwestern side of this basin is now devoid of interest, as long as the outcrop from Someș-Odorhei (CODREA & GODEFROIT, 2008) already vanished and the Maastrichtian locality Iara yielded only a single bone, found nearly a century ago.

In these localities, for each outcrops of interest – both for paleontology and sedimentology – 3D images will be yearly achieved during a decade, the photogrammetry being done from same locations. In this manner, the transformation tendencies will be easily detected. The 3D images will be stored in a database at the Department of Geology of Babeș-Bolyai University Cluj-Napoca. If this work will confirm its target, one can continue even further in time, on several successive decades. After a time, a valuable image database will be available for all geologists interested on the island evolution occurred in the Maastrichtian of Transylvania and on the paleogeographic turnover that happened in the Tethyan archipelago, where a lot of peculiar invertebrate and vertebrate taxa probably had their cradle.

## ACKNOWLEDGEMENTS

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## 3D GEOLOGICAL MODELLING FOR GROUNDWATER MANAGEMENT IN CARDONA

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**KEY WORDS:** 3D geological modelling, management; groundwater.

### ABSTRACT

In the long history of the mining development of the Cardona's diapir, in Vall Salina (Cardona, Catalunya, NE Spain), there have been multiple episodes of groundwater inflow into the mine caused by the interception of karst conduits. Nowadays, the operation is done with a continuous drainage from the mine. In addition, the water surface of the tertiary aquifer is altered. Since 2011, the Institut Cartogràfic i Geològic de Catalunya (ICGC) has launched a project to improve the management of groundwater. In this context, a 3D geological model of the tertiary detrital units is being developed to ensure a better understanding of the geological structure and its effect on the groundwater flow dynamics. This 3D geological model should be a basic and fundamental new tool to improve the management of groundwater.

### INTRODUCTION

Throughout the long history of the mining development of the Cardona's diapir, there have been several episodes of groundwater inflow due to the interception of karst conduits. Over the years, the karst development resulted in 1997 the hydraulic connection between the alluvial aquifer and the mine, causing environmental and operation problems in the mine. To minimize them, several activities were carried out: the diversion of the Cardener River in 2000; building impermeable subsurface barriers in order to restrict the movement of groundwater flow into the mine; groundwater dewatering wells, etc.

Since 2011, the ICGC (ICGC-GEOCAT, 2012) has launched a project to improve the management of groundwater. This project focus

on these following issues: better understanding and control of groundwater; conducting proper monitoring; and improving the geological understanding. In the current phase, a 3D geological model of the tertiary detrital units is being developed to provide new tools for analysis and resolution.

### GEOLOGICAL SITUATION

The study area is located in the Meandre de La Coromina, in the NE of the Vall Salina, Cardona, where the valley merges with the old bed of Cardener River.

The core of the Cardona's diapir outcrops in the Vall Salina. This salt anticline is a part of a SW-NE folding system. In the Meandre de La Coromina area, it has a plunge towards the NE. The closing periclinal of the fold and the NE boundary of the diapir make it visible.

This predominant structure of the basement is faulted, including perpendicular faults on the direction of folding. These ones do not just increase the NE termination of the diapir, but they would also be decisive for the karst development (Font, 1985). There are also E-W faults, detected basically on drilling works.

The materials involved belong to the Upper Eocene - Oligocene: the diapir's core is made up of the evaporitic deposits of Fm.Cardona and the overlying units are constituted by sandstones and marls of Fm.Súria and Fm.Solsona. The tertiary basement is partially covered by quaternary deposits which are alluvial-colluvial, in the margins of the valley, and fluvial in the Cardener's area.

### METHODOLOGY

With the purpose to generate a 3D geological model of the tertiary detrital units, a workflow has been taken into account following these steps:

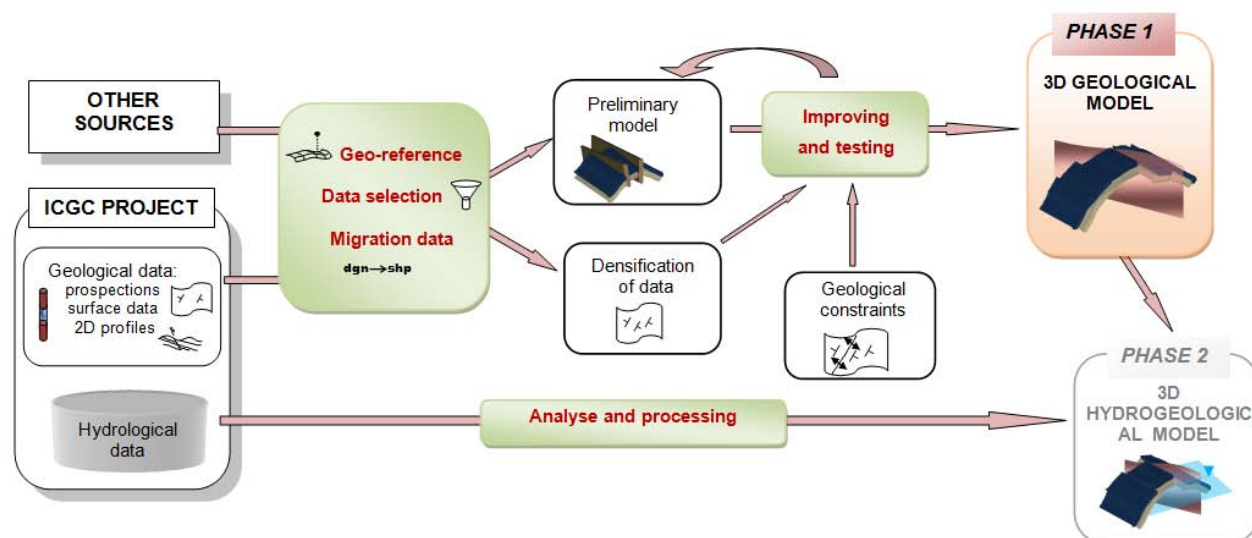


Figure 1 – Workflow to construct the 3D geology model.

- Compilation and geo-referencing of primary data.  
The monitoring project has allowed us to collect a set of important information. In addition to the hydrogeological data (transmissivity data, piezometric measures...), a set of geological information has been obtained such as multiple drilling works made for different purposes (piezometers, dewatering wells, etc.). In particular, 8 inclined boreholes, drilled between 1933 and 1954, in order to delimit the NE boundary of the diapir, under the alluvial materials. Moreover, as result of multiple explorations, surface data have been gathered, including dip data and surface cartography. Finally, some 2D cross-sections have been generated as basic tools for the visualization of the geological structure.
- Analysis of primary data according to their utility for the future 3D model.
- Migration of the data, from 2D to 3D. Previously, the data had been processed from CAD (DWG, DGN) and GIS (shape files) environments, because of their high interoperability and easy handling. To integrate the new software, there has been an adaptation of formats and content information.
- Generating the 3D model using specialized software: GOCAD by Paradigm and MOVE by Midland Valley. Based on the structural analysis of the data, a preliminary model has been generated using the dip-domains method (Gronshong, 1999).
- Improving the model with the densification of the data and the addition of geological constraints. Moreover, in the process of modelling, various interpolations were tested in successive iterations. The outcome is a deterministic structural model with the creation of several surfaces (lithological contacts and faults) which show the structure of the subsurface.
- Transformation of the generated 3D surfaces into meshes, contour maps, etc. for 3D visualizations or being used in flow models.

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## ASSESSING THE POTENTIAL OF IMAGING SPECTROSCOPY APPLIED TO GEOLOGICAL MAPPING IN THE MONTSEC AREA (PYRENEES, SPAIN)

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**KEY WORDS:** *Imaging spectroscopy, hyperspectral remote sensing, geological mapping, Montsec, Pyrenees.*

### INTRODUCTION

Remote sensing has direct applications in hydrocarbon exploration by assisting in the generation of geological models. In particular, imaging spectroscopy, that acquires simultaneous images in many spectrally contiguous bands, have lately achieved a widespread use. However, the use of hyperspectral images for geological mapping purposes is not without limitations. The aim of this paper is to evaluate the quality and the degree of confidence using image spectroscopy in hydrocarbon exploration and production workflows. For that purpose a hyperspectral airborne flight has been acquired over the Montsec area (Pyrenees, Spain).

### DATA SET

The airborne data were acquired on the 5<sup>th</sup>, 11<sup>th</sup>, 16<sup>th</sup> and 17<sup>th</sup> July 2014. The used sensor, AisaEAGLE II (Specim), acquires hyperspectral data with 1024 swath pixels and high image rates in the Visible-Near InfraRed (VNIR) wavelength range (400-970 nm). Spatial resolution of the acquired image is of 1m and it has a total spectral resolution of 128 bands. Pre-processing of the data consisted in: radiometric and geometric corrections, georeferencing the images and perform the atmospheric correction with version 5.0 of MODTRAN software. A field survey to obtain ground truth data with the spectroradiometer FieldSpec3 (ASD Inc.) was carried out. A total of 303 spectral signatures were measured in the field.

### IMAGE PROCESSING AS A GEOLOGICAL MAPPING TOOL

Image processing consisted in an interpreter-oriented sequence of spectral unmixing routine with standard algorithms procedure for feature extraction. The standard sequence of algorithms consists in: Minimum Noise Fraction transforms, Pixel Purity Index and n-Dimensional Analysis to extract significant statistical populations (RSI, 2004). A land use map was computed with Spectral Angle Mapper (Kruse et al., 1993) using the appropriate end members (Fig. 1A). These end members were finally used to perform a comparative score of similarity with the Spectral Analyst (RSI, 2004) and the ground truth data acquired in the field as a reference (Fig. 1B) to build a geological map of the area (Fig. 1C).

### RESULTS AND DISCUSSION

Results show that, despite requiring a thorough processing, hyperspectral images can be a detailed and reliable tool to produce geological maps. Spatial resolution of the AisaEAGLE II images has clearly allowed us to map stratification and lateral facies changes below the resolution of a conventional geological map (scale 1:50000). This has been possible despite having limited spectral resolution images. This is, covering just a fraction of the VNIR wavelength range (400-970 nm) and lacking of part of the VNIR (970-1200 nm) and Short Wave InfraRed (SWIR; 1400-2500 nm) wavelength ranges, which is the fraction of the electromagnetic spectrum where geological materials show more spectral absorptions features when electromagnetic energy interacts with their components due to vibration and absorption phenomena.

## CONCLUSIONS

The resulting geological map is an image of variable reflectance of the scene and was constructed by interpreters who are able knowledgeable of the geological context on the Montsec area. Thus, making the results very site specific, implying that there is no single recipe that is universally applicable. Conventional geological

mapping skills and geological interpretation of aerial photography are required to validate maps produced through image processing. Finally, geological mapping by means of hyperspectral image interpretation can be used in exploration and production workflows (development/appraisal stages) as a reservoir evaluation tool at a reasonable cost/benefit.

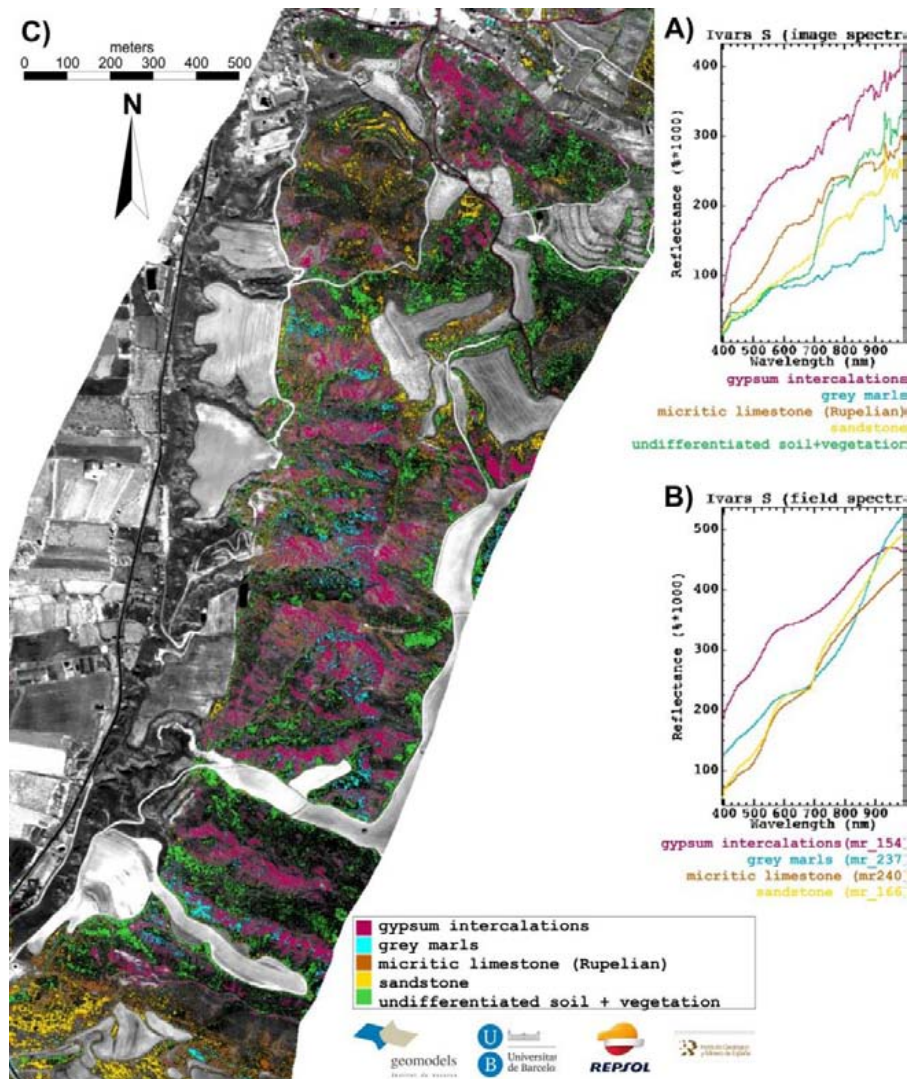


Figure 1 – (A) Spectral signatures of the AisaEAGLE II image used as appropriate endmembers in the Spectral Angle Mapper (Kruse et al., 1993) obtained after the successive steps of the image analysis process described in the 'Image processing as a geological mapping tool' section. (B) Spectral signatures (ground truth data) acquired in the field with the FieldSpec3 (ASD Inc.) used as references with the Spectral Analyst (RSI, 2004) to obtain a comparative score of similarity for image spectra selected as endmembers. (C) Final geological map obtained from the analysis of the AisaEAGLE II hyperspectral image.

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# SEISMIC INTERPRETATION AND VISUALISATION FOR A 3D MODEL IN THE SOUTHERN BALTIC SEA WEST OF RUEGEN ISLAND AS PART OF THE USO PROJECT

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**KEY WORDS:** *Baltic Sea, Mecklenburg Western-Pomerania, Germany, off-shore 2D seismic, North German Basin, fault systems, Grimmen anticline.*

## MOTIVATION

The creation of 3D subsurface models of the Baltic Sea area west and east of Rügen Island are the major issues of a research project between the Geological Survey of Mecklenburg-Western Pomerania (LUNG M-V) and the University of Greifswald called USO ("Untergrundmodell Suedliche Ostsee").

## DATA BASIS

The subsurface of the project area in southern Baltic Sea was the subject of intense oil and gas exploration by the former organization "Petrobaltic" in the 1970ies and 1980ies. Numerous 2D sea-seismic data have been measured. 86 of these seismic profiles within an off-shore area west of Rügen Island with a whole length of approximately 1500 km were re-processed to improve the resolution of deeper horizons and reduce disturbing factors like multiples.

## PROCESS STEPS

The first step was to interpret each seismic line, using the "SeisWare" software package. Crosscutting lines allows a quality control like to prove the consistence for each picked horizon. Afterwards, relevant horizon tops, e.g. Rotliegend, Zechstein, Buntsandstein, Muschelkalk, Keuper as used by ZOELLNER et al. (2008) and the base of Cretaceous were gridded using Kriging.

First results were visualized in the "SeisWare - 3D Visualizer". Gridded horizons together with triangulated faults of the dominating fault systems give a first overview how a 3D model would look like. These preliminary results reveal that the sedimentary deposits at the north-eastern margin of the North German Basin (NGB) are mainly

characterized by successions of Permo-Triassic age with a thickness of 300 to 1200 ms (tw). Jurassic to Cretaceous sediments occur only subordinate and their thicknesses differs locally due to differentiation into local swells and sinks or as a result of inversion tectonics during late Cretaceous to Palaeogene times, e.g., the Grimmen anticline (KOSSOW 2002).

A lot of complex fault systems are visible, which were discussed by KRAUSS & MAYER (2004). The detailed analyses suggest that the Werre and Prerow fault systems in the south are related to a detachment which influenced all horizons between Upper Permian and Jurassic. In contrast, the Agricola fault system consists of a sub-parallel set of faults within the Mesozoic deposits reaching downwards into Late Permian sediments. In the northernmost part of the study area the deep rooted Odense-Wiek fault system marks a sharp tectonic boundary between deposits of the NGB and the uplifted Arkona block, which is built up by faulted and folded Palaeozoic sediments discordantly overlain by sediments of Upper Cretaceous age.

## OUTLOOK

The last step is a depth migration of the time-based horizons into depth-based layers. Afterwards, all generated grids and triangulated fault systems will be integrated into GOCAD to build up the 3D model.

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## 3D FACIES MODELLING STRATEGIES IN LARGE FAN-DELTA RESERVOIRS AND THEIR IMPLICATIONS IN PREDICTIONS. DATA FROM MONTSERRAT AND SANT LLORENÇ DEL MUNT OUTCROPPING ANALOGUES (EOCENE, NE SPAIN)

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**KEY WORDS:** *fan delta, 3D facies models, reservoir analogue, sequence stratigraphy.*

### INTRODUCTION

During the last decades, 3D models of subsurface geological heterogeneity have proved to be important tools for the efficient management of hydrocarbon reservoirs (Castellini et al. 2003, Jian et al. 2002). The construction of accurate 3D facies models from outcrop data has become a useful method to reduce uncertainty in real subsurface reservoir studies, since those models of outcropping analogues provide with data and can be used to test and/or define modelling strategies.

Previous works modelled facies belt distribution in the Sant Llorenç del Munt complex at production scale based on outcrop data (Cabello et al. 2010). In the present work, a new outcrop-based exploration scale 3D facies model including the production scale model area is presented. The total area comprises both the Montserrat and the Sant Llorenç del Munt fan-delta complexes which were deposited during the Eocene in the SE Ebro basin margin. The depositional stratigraphic record of these fan deltas has been studied and described as made up by several transgressive to regressive Composite sequences, each defined by the stacking of several high-frequency Fundamental sequences (López-Blanco et al. 2000). Stratigraphically, the model includes the record of three of those Composite sequences, representing a stratigraphic thickness in the order of 325 m, and it covers an area of 25 km x 15 km.

### METHOD

Input data consisted of geological maps at scale 1:10.000 (López-Blanco & Piña 1992/93), georeferenced digital terrain models (5m x 5m of resolution) and orthophotographs (pixel size of 25 cm) by the Institut Cartogràfic de Catalunya. The horizon framework of the model was based on the key surfaces associated to the Composite

sequence scale subdivision, bounding transgressive and regressive sequence sets. Their traces were digitized onto the photorealistic terrain models, and the derived altitudes were used to elaborate contour maps of each key surface. Those maps were the base for the 3D reconstruction of key horizons. Since the succession is affected by a number of N-S oriented faults and also a series of thrusts related to the SE basin margin, faults were included in the model. A total of nine vertical faults and two thrusts were reconstructed.

The 3D volume delimited by the key stratigraphic horizons and the faults was gridded. Dimensions of the 3D grid cells in plain view were 100 m x 100 m and their faces were oriented following the mean sedimentary paleoflow direction (320°). A proportional layering was selected with a mean cell thickness of 1.75 m, resulting in a 3D grid of 7.5 million of cells.

The facies modelling aimed to reproduce the stratigraphic distribution of the main facies belts which are present in the fan-delta complexes (thrust-related alluvial breccias, proximal alluvial fan, distal alluvial fan, delta front, carbonate platform and prodelta) (Figure 1). Terrigenous belts were modelled using the algorithm based on the truncation of the sum of a deterministic expectation trend and a Gaussian random field (TTG; MacDonald & Aasen 1994; Falivene et al. 2009). This process was guided by the elaboration of a series of paleogeographic maps showing the facies belt location just below and above each key surface.

Carbonate facies have a discontinuous presence and are associated to high-frequency transgressive events. This facies was modelled as ellipse-shaped geobodies using an object-based algorithm. Its distribution was fixed attending on the nature of the sequence set (40% of volume in the transgressive and 10% in regressive), and its position was constrained to be within the distal delta front and proximal prodelta (sub-facies belts specially considered for this purpose).

Ten realizations of this model were obtained.



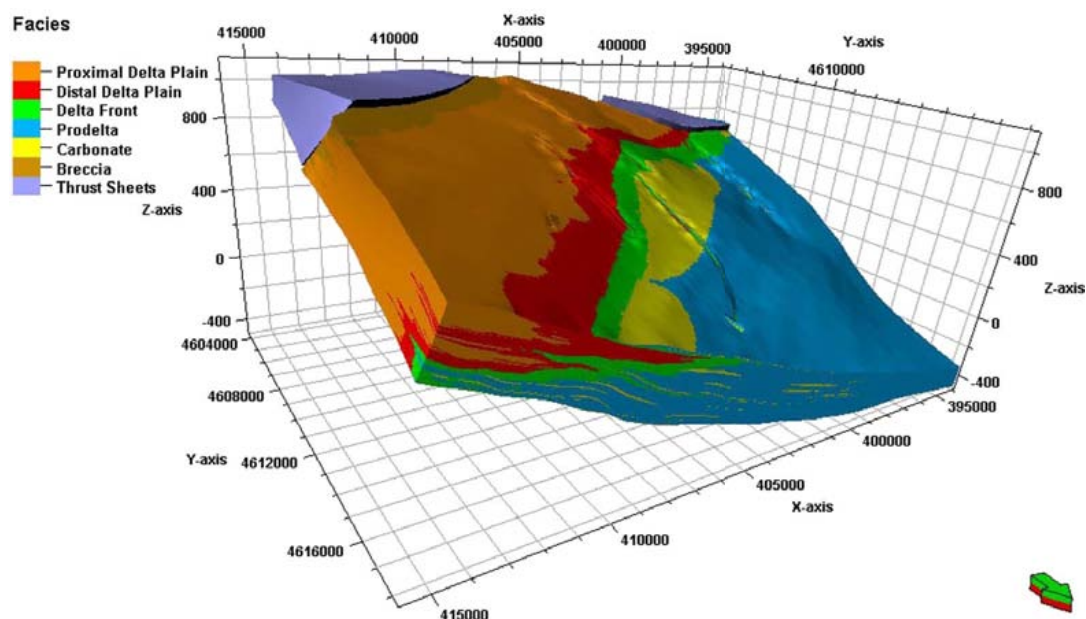


Figure 1 – 3D facies model of Sant Llorenç del Munt and Montserrat fan delta complexes. Coordinates are in Universal Transverse Mercator (UTM) zone 31. Vertical exaggeration is 6x.

## CONCLUSIONS

An exploration scale facies model (375 km<sup>2</sup> and 325 m thick) of two outcropping fan-delta complexes was produced. This model reproduces with detail the heterogeneity associated to the T-R cyclicity at two scales, and thus the modelling strategy could be applicable in the subsurface.

This 3D exercise can be used to document the architecture and distribution of reservoir analogue facies belts. The fan-delta front is a sandy and conglomeratic facies belt, bounded by muddy continental and marine units, and it could be the potential reservoir rock. Fan-delta front facies maps extracted from the model shows maximum accumulated vertical thicknesses of about 135 m, preferentially concentrated in the central part of the study area following a trend parallel to paleocoastline. The model reproduces a continuous delta front facies belt connected along the different sequences. In spite of this, its complex geometry could also capture the existence of potential stratigraphic traps related to the endings of fan-delta front wedges into prodelta and distal alluvial mudstones resulting from the cyclicity at different scales.

## ACKNOWLEDGEMENTS

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## THREE-DIMENSIONAL GEOLOGICAL MODELING WITH GIS INTEGRO USE

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**KEY WORDS:** GIS, three-dimensional modeling, geological map construction, solving of geological problems

### INTENT, STORAGE AND VISUALIZATION

The geoinformation system INTEGRO has been developed by State Science Centre of Russian Federation VNIIGeosystem (Moscow). The system is capable to visualize and process different types of geological information (geological maps, geophysical and geochemical data, aero and satellite images, drilling information, geological and geophysical sections, three-dimensional data, and so on). INTEGRO is intended for solving problems of geological map construction, forecasting mineral resources, study of the deep structure of the Earth, and three-dimensional territory modeling.

For the joint visual analysis of the various information types, the system is multi-window and is equipped by the synchronization mechanism in different windows. This mechanism works when there is the visualization of three-dimensional objects too, and also in that case when localization of the data does not coincide (for example, the surface data, the section data, and the drill information). There are tools allowing user to change spatial localization (to represent the two-dimensional data, for example seismic section, as a three-dimensional objects). There is base-level easy integration with ESRI software because data format of the system is shape file, and the conversion of styles between systems is done.

### STRUCTURE

GIS INTEGRO contains units which perform different functions. There are tools in the system allowing user to carry out a vectorization of maps in automatic and semi-automatic modes. For the vector data the correct topology checking and overlay operations are supported. It is possible to keep not only intralayer, but also interlayer topology while editing. There are implemented procedures of a fast binding and transformation of raster and vector maps by affine and piecewise-affine transformations. The comprehensive set of cartographic projections is supported. There is a block for information transform from vector to grid.

The forecast block, including in a three-dimensional variant, is developed. For study of the deep structure of the Earth there is the gravimetric and magnetometric information processing block. It includes:

- statistical analysis of the two-dimensional information,
- division of two-dimensional and three-dimensional fields into components using methods of linear and nonlinear filtration,
- detection of weak anomalies of two-dimensional fields,
- calculation of statistical and correlation characteristics of two-dimensional fields.

The system also contains the modules designed for solving various assignment formulations of gravimetric and magnetometric direct and inverse problems and also modules of analytical extension of potential fields.

### THREE-DIMENSIONAL TERRITORY MODELING

The technology of three-dimensional territory modeling is based on the implemented tools. For creation of three-dimensional territory model the geological map, drilling data, seismic profiles, gravimetric and magnetometric information is used. There is a module for constructing a three-dimensional model of the layered structure with regard to thinning according to the drilling.

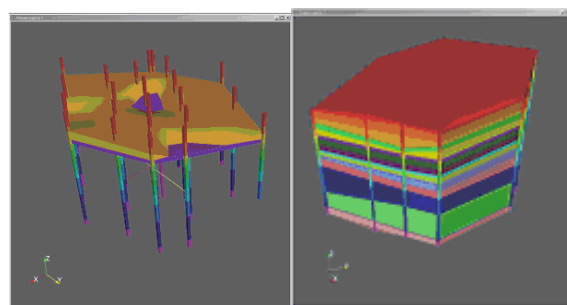


Figure 1 – Constructing of three-dimensional model with regard to thinning.

If there isn't enough data, GIS INTEGRO can construct the system of profiles. It is possible to provide in the automated mode only the model of a section, with drawing of the main geological divisions of the map according to basic rules: capacity of a layer is supposed constant; the

bedding of layers is supposed similar; the sequence of layers is identical. For creation of a profile in the system is based on a surface relief, a column of capacities, profile crossing with geological divisions, disjunctive objects, and so on (fig. 2). May be used more information about downthrows and upthrows, also may be given a function which describes change of units power along the cut. The system of resulting profiles thus can become unmatched. Thus the expert-geologist has to harmonize them (fig. 3, left). Therefore the editing subsystem is used. This subsystem provides simultaneous editing of several scenes, for example, three profiles in a point of their crossing. After the adjustment the structural surfaces of a sedimentary cover interpolation is made (by profiles and outcrops to a day surface). There are the special methods of interpolation, which use a thin network, take into account breaks and restriction of area of interpolation (fig. 3, right).

Using the tools of the system, there is created the technology for constructing block-layered model, based on gravimetric and magnetometric data. By the means of the geophysical information processing block three-dimensional models of superfluous density and effective magnetization can be calculated, as well as a resulting relief of a

base surface, and further carrying out their combined visual analysis with the geological information. The algorithms of the forecasting block are applied for that. So decomposition blocks of the base and petrophysical characteristics of the resulting blocks are the result of this process. Then information about the deep structure can be used for forecasting.

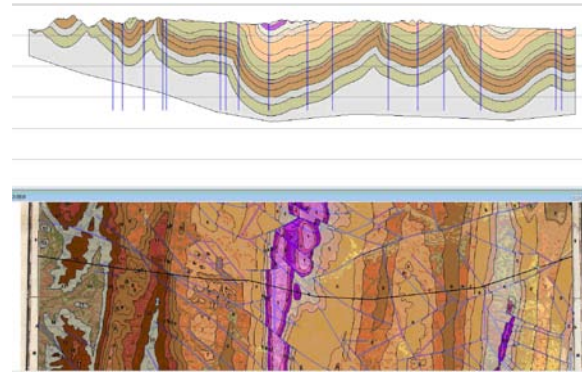


Figure 2. Section (above) constructed according to the geological map (below).

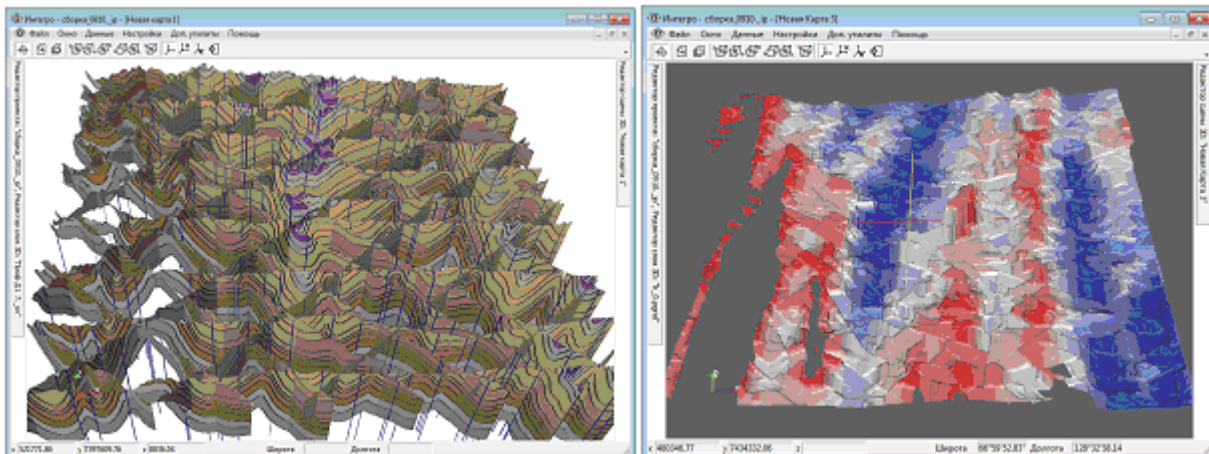


Figure 3. Harmonization and editing of geological sections (left). Transition from sections to surfaces (right).

## CONCLUSION

In conclusion we will list the basic advantages of GIS INTEGRO:

- INTEGRO has multi-windows user interface that supports data synchronization of the different windows that allows user to conduct visual analysis and data integration (including various spatial localization data);
- INTEGRO is based on ESRI vector data format (shape file);
- INTEGRO supports possibility of information binding and re-projection, contains a wide set of projections;
- INTEGRO contains a block for geophysical information processing and a forecasting block;
- The technology of a geological section construction based on a surface relief, a column of capacities, profile crossings with geological divisions and disjunctive objects is developed;
- On the basis of the created tools the technology of the territory three-dimensional modeling is developed.

## 3D Geological modelling application in a contaminated site.

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**KEY WORDS:** 3D geological modelling, contaminated sites, open source, Qgis, GRASS.

### ABSTRACT

Geological modelling can represent an important change in relation to drainage interventions on polluted sites. The 3D geological model described in this abstract was built with stratigraphy data and geo-physical investigations that were realised through the characterization phase and the superficial geological surveys. The application entails a multidisciplinary approach that includes the integration of direct and indirect testing to achieve a tridimensional geological mode. The model provides information about the overall conditions of the substratum as well as offering useful information that can be used to understand the dynamics, the migration and the propagation of contaminants inside the soil.

### INTRODUCTION

The environmental characterization is the first and foremost important phase of drainage interventions of polluted sites. Its aim is to define the conceptual model of the site which provides information about the migration and the propagation of the contamination in various soils. Besides, it defines an action plan for the following phases.

The geological investigation activities that we propose here are aimed at re-building and modeling (in 3-D) the geological bodies that host contaminated sites. These are carried out as part of a larger project which has as its final goal the testing of new models. The geological modeling in 3D represents an effective means in order to overcome the limits of the bi-dimensional cartographic representation. Specifically, in this representation, only part of the collected and coded data is represented in the map or in its framed sections, determining a loss of information. The applied methodology provides a useful tool for the integrated management of multi-z and multi-scale as well as for the use of existing databases (D'Ambrogi, 2009).

Moreover, 3D geological modeling constitutes a tool for synthetic data analyses and geological knowledge that favours the understanding of the geological reality; it further ensures that a more complete analysis of geological phenomena can be carried out. In our case, the 3-D modeling has rendered a more efficient representation of the geological structures of the contaminated sites under investigation, that is the RSU dump situated in municipality of Baronissi (southern Italy). Tridimensional geological modeling software, as the one used in this study, is able to deal with large sets of geological data in relation to surface and substratum. It allows the user for visualization and interaction with data, with the purpose to analyse precise and complete relations among data. The resultant 3D model allows for controlling data coherence and for verifying the spatial relations of the unit. For the site under examination, the database collected data deriving from geognostic (carotage and stratigraphy) and geophysics investigations (electric tomography, geo-electric investigation).

The development of our methodology includes (see Figure 1):

- A first phase for the recovery and re-cataloguing of the data of the area, further selecting those that are useful for the 3D geological model
- A second phase that is the processing of the data in order to realize the dataset, in which data are geo-referenced and digitalized, through open source software called Qgis. The GRASS open source software is a powerful instrument in various research fields in natural science (Neteler, 2012)
- Once the data have been processed, single data was used to generate geological models of the surface and structures as well as topographic surface.
- Following the first three phases, a 3-D geological model was created.

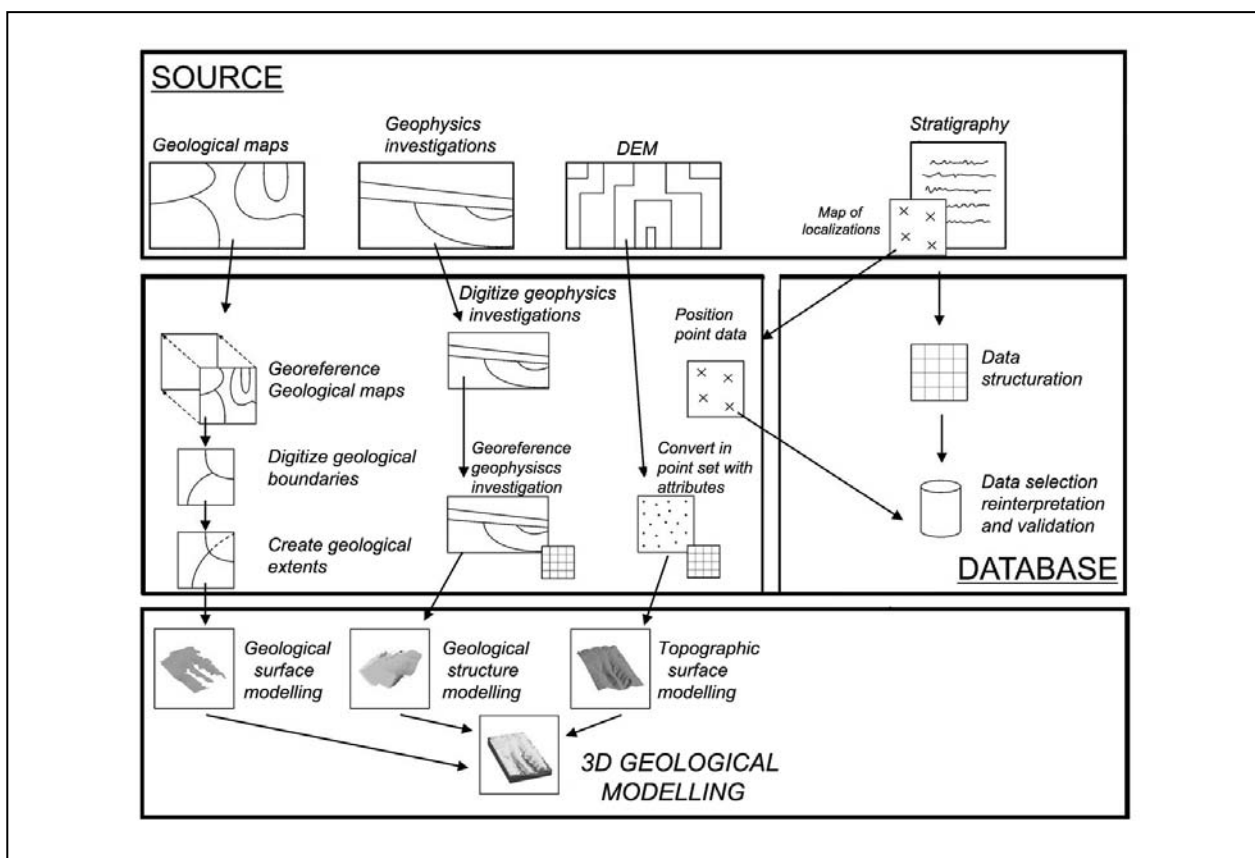


Figure 1 – Organigram of methodology developed.

The 3D model of the contaminated site based in Baronissi highlighted that the waste body is laying on an eluvian-colluvian blanket of increasing thickness towards the valley. Moreover such blanket leans in the southern edge of a nearly vertical fault. Therefore the site is contained in asymmetric tectonic depression of dolomite and dolomitic limestone of significant thickness.

This re-construction has allowed for the understanding of the direct contamination within the blanket as well as along the fault and the subordinate fractures connected to dolomite rock.

#### ACKNOWLEDGEMENTS

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## New tools for the study of high-resolution digital outcrops oriented to the 3D geological models.

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**KEY WORDS:** LIDAR, Photogrammetry, Geological Models, Virtual Outcrops, SfM.

### Abstract

LIDAR (Light Detection and Range) and photogrammetry are techniques used to capture geological outcrops and elaborate Digital Outcrop Models or DOMs (Lato et al., 2013). In the last decade, the continuous technical improve applied in both techniques have achieved to be introduced in the workflows of many geoscientists to extract geological and engineering data from them.

Terrestrial LIDAR or Terrestrial Laser Scanner (TSL) allows capturing the topography of the surface outcrops with high resolutions or densities (about one survey point by centimetre or decimetre) directly and with very fast acquisitions (minutes). On the same way, the photogrammetry technique has evolved with the Structure from Motion (SfM) (Ullman, 1979) process that allows acquires surfaces outcrops with similar resolutions to LIDAR solutions. Unmanned Aerial Vehicles (UAVs) or drones are loaded with digital cameras enabled to be processed with SfM technique.

The final purpose of capturing DOMs can be the extraction of geological features to analyse geological and engineering processes. Mechanical discontinuities, volcanic studies, stratigraphic modelling or landslides are examples of applicability. Tools for these extractions are time-consuming and users must have good computer skills to obtain high-quality results. In order to solve this situation, a series of tools have been developed to identify features whether by a semi-automatic method or directing digitization of 2D images to extract 3D data.

### Introduction

The captures of geological outcrops by LIDAR or SfM techniques achieve to dispose of High-Resolution Digital Models or Point Clouds with a high density of information to geological purposes. The knowledge of both techniques allows selecting the best technique or combine techniques to achieve the best DOM. The required high qualification of the users and the high cost of LIDAR technique is compensated by a high accuracy in their results and the quality in terms of

reliability, density and visualization. SfM offers lower costs as it can work with simple digital cameras. Photogrammetric data processing is easy for the users with acceptable accuracies in results and the cameras can be allocated in UAV's as a payload. Indifferently of the technique employed, or combining both techniques the point cloud obtained must be processed to extract data.

Available software applications from commercial or open sources approaches offer several solutions still insufficient from a geological and engineering point of view. With the aim of integrate extracted data in geological models, Geomodels Research Institute develops specific tools to fill this gap.

### Data capture

The LIDAR is a common surveying technique since the last decade (Slob & Hack, 2004).

High technical requirements by the photogrammetry have been simplified with the SfM technique to capture High-Resolution outcrops. The improvements come from the implementation of algorithms as SIFT (Lowe, 2004), SURF or the Semi-global Matching in digital photogrammetry processes. These algorithms are incorporated in open source and commercial software reducing the technical requirements of the users. The digital images used by the SfM process can be taken with digital cameras by the users or mounted in boats, vehicles or UAVs. In aerial cases, the camera orientation can be zenith along 30 or 50 minutes of time flight in airplanes and zenith, oblique or horizontal along 15 minute of time flight in multicopters. New points of view are captured for vertical outcrops or great extensions of terrain.

Photogrammetric and LIDAR point clouds can be combined over a single outcrop to overcome terrain inconveniences or technical limitations.

### Data Extraction

Geological data extraction from point clouds is the purpose for the outcrops capture. Solutions for this extraction are implemented with manual, supervised or automatic proposals from different software either commercial as open source. The

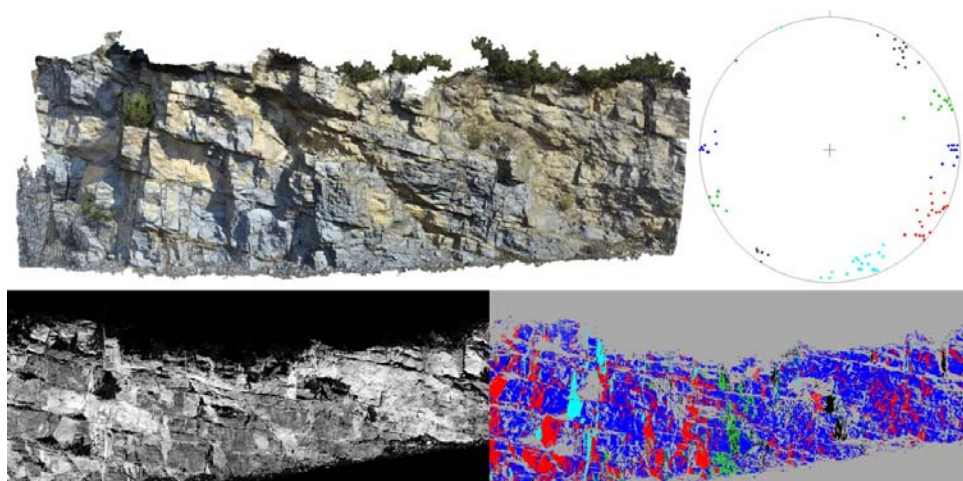


Figure 1 – Upper left: Outcrop orthoimage (length: 27 m Height: 7 m) SfM orthorectification. Upper right: Corresponding stereoplots of the five main fracture sets. Lower left: Laser scanner section with TLS Intensity. Lower right: Point Cloud image after identify and classify surfaces by fracture set orientation SEFL software. Example Middle Eocene Añisclo anticline (Southern Pyrenees).

most employed methods are the manual digitization over the point cloud in a 3D environment or the automatic triangulation to obtain surface orientations. Limitations on the results and along the process led us to develop our own solutions:

*Surface identification tool* used to calculate planar regression of point cloud and based on the moment of inertia analysis for neighbouring points, implemented in SEFL software (Garcia-Sellés et al., 2011). A set of complementary tools has been added to reconstruct surface from these planar regressions (Santana et al., 2012). Fracture or stratigraphic surfaces are identified and extracted to integrate in a geological model

*Trace identification tool* allows drawing objects (i.e. points, lines or polygons) over the 2D colour images to extract 3D traces from the point cloud (Geyer et al., 2015)

*Fracture Characterization tool* creates virtual Scanlines along the point cloud processed with the previous tools to characterize fracture sets automatically after the surface reconstruction. Characterization results can be used as input data in Digital Fracture Networks (DFN).

## Conclusions

High-resolution digital outcrops are useful for many geological applications. LIDAR and photogrammetry being techniques with a high degree of reliability to elaborate point cloud. Our tools developed supplies the lack of efficient automatic tools for data extraction.

## ACKNOWLEDGEMENTS

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## 3D MODELLING OF RÍO TINTO AREA. NEW INSIGHTS INTO ITS GEOLOGICAL STRUCTURE.

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**KEY WORDS:** Iberian Pyrite Belt, South Portuguese Zone, Río Tinto Mine, structural geology, 3D geological model, gOcad, VHMS ore body.

### INTRODUCTION AND GEOLOGICAL SETTING

The aim of this study is to obtain the characterization of the geological structures in Río Tinto mine (SW Spain) and their 3D modelling.

The Iberian Pyrite Belt (IPB) is a Variscan metallogenic province in SW Iberia hosting the largest concentration of massive sulphide deposits worldwide. The IPB has a relatively simple stratigraphic column that consists of three major lithostratigraphic units (Schermerhörn, 1971).

The lowermost stratigraphic unit is the early Givetian to late Famennian Phyllite-Quartzite Group (PQG), with shales, quartz-sandstones, quartzwacke, minor conglomerate and limestones at top. Over them, the volcano-sedimentary complex (VSC), that comprises a submarine volcanic succession, with VHMS deposits. At the top there is thousands of meters thick Baixo Alentejo Flysch (CG) of late Viséan to Moscovian age. To the East of the IPB, there are subvolcanic-plutonic rocks, the Sierra Norte Batholith (SBN), which represents the continuation of the VSC. The SBN includes geochemical associations of mafic rocks (gabbro-diorite) and granitoids with TTG affinities (Díez-Montes et al., 2008). Tectonically, variscan NW-SE/W-E-trending and SW/S-verging folds and thrusts occur in western/central and eastern IPB, respectively. In late to post-Variscan time strike-slip oblique faults formed, either N-S to NNW-SSE or NE-SW to ENE-WSW, dextral or sinistral (both extensional), respectively.

### DATASET AND 3D GEOLOGICAL MODEL

The construction of a 3D model has contributed to a better understanding of the complex structure of the Río Tinto zone. Several kinds of data have been used in this study (Figure 1A).

**Topographic data** has been imported as points from a digital elevation model. An updated survey has been used, that covers the area immediately next to the site of mining interest.

New data has been included to cover the zones outside the mining area. The cartography produced by the ICA (Cartographic Institute of Andalucía) was chosen. The topographic surface has been built in the gOcad software.

A new **geological map** of the area has been made, from which linear and polygonal features representing stratigraphic, tectonic and intrusion boundaries were taken. At the same time, 44 **cross sections** have been interpreted as input for the modelling, with special focus on the Río Tinto anticline. **Petrological and petrophysical** samples were taken for laboratory determination of properties (densities, magnetic susceptibilities), and natural gamma ray-measurements.

Existing **geophysical coverages** were densified with new acquired data, consisting of gravity and natural gamma ray data. From the analysis of the variations in density and magnetic susceptibility distribution in depth by potential field modelling, 17 new geological cross-sections were created. For this task we have used the latest GM-SYS software (by Geosoft).

Other data used were from drill-holes and old maps, vertical sections, and horizontal slices of ore-bodies. In Río Tinto area several classified **documents from mining activities** have been made available, which has allowed the reconstruction of historical ore bodies. The mine plans by level contain the mine works at each level of the mine, with survey geochemical data, lithological interpretations and maps, from which the sulphides masses have been drawn. Sections of the masses have been incorporated when available.

The model has been constructed in gOcad from the **horizons** and **faults** surfaces generated as medium planes of each set of curves for each top and each fault and shaped using the DSI (Discrete Smooth Interpolator). To achieve this, the constraints to that curves has been established. Local edition has been necessary where some conflict has been detected, especially in reverse faults zones. Among all the existing faults, only the most relevant have been chosen. Horizons have been cut by faults and constraints



in faults borders have been established in order to recreate the fault slips (Figure 1B).

The **massive sulphide bodies** are created as surfaces constructed by triangulation between the outlines from consecutive plans. Constraints were set to the outlines, and later interpolations led to smoother surfaces.

Several simulations have been performed, in order to see the relation between the content of some elements and the geological structures. A SGrid of 79,692,500 cells of 5x5x1m has been made and adapted to the volume defined by the volcano-sedimentary series. The method of interpolation used is again DSI. Grades of the

elements are hold as properties, transferred to the cells prior to the interpolation. Analytical contents of several elements of economic interest were available (Cu, S, Pb, Ag and Zn). The correspondence between the zones of high grades and the ore-bodies is clear, while there is a spread of the grades in the area due to the stockwork and the chloritic alteration present in the central part of the anticline (Figure 1C). The original data were taken from drilling campaigns previous to the open-pit. The upper part of the structure is not present today, so, they have been useful to reconstruct the previous copper distribution.

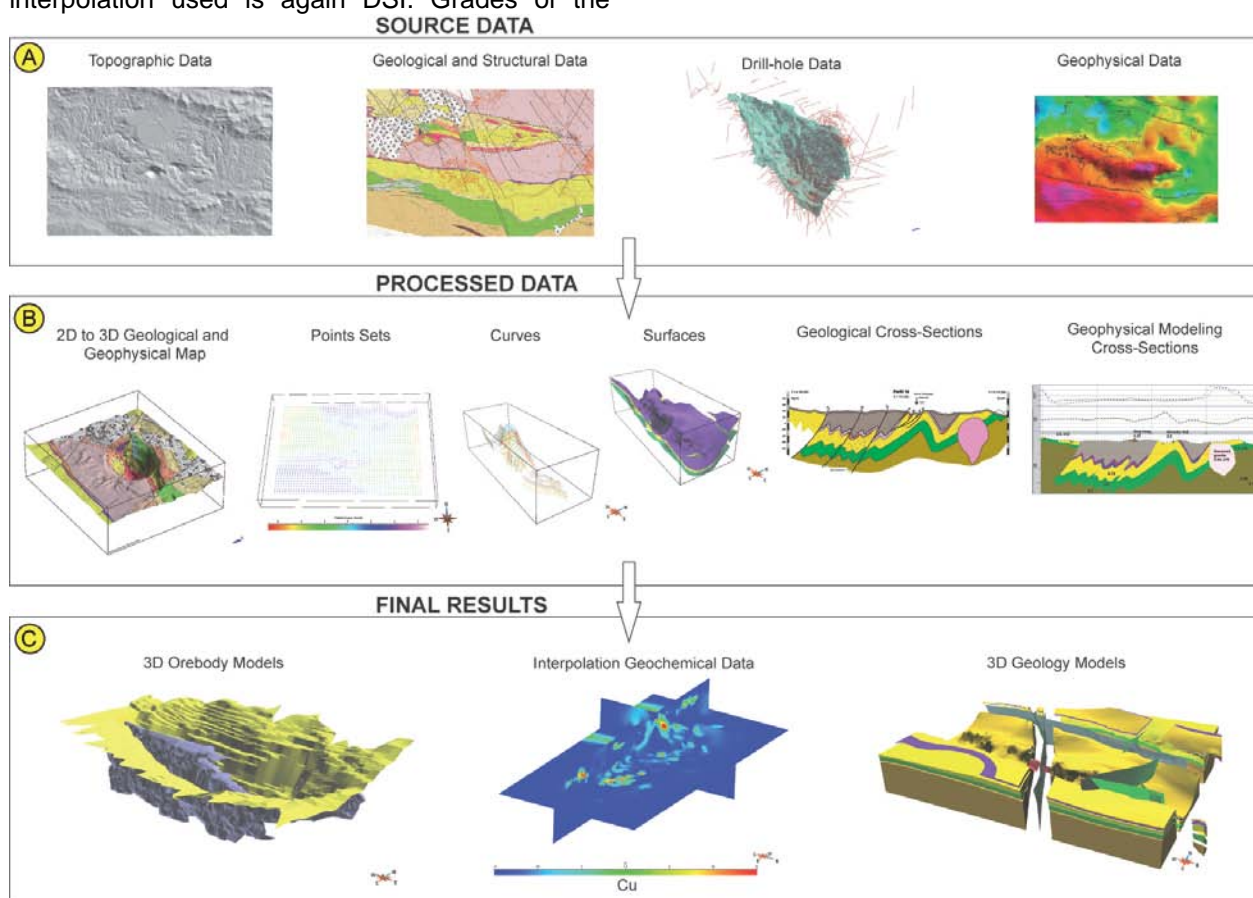


Figure 1 – Schematic flow-chart for 3D modelling through data integration between source data, GIS, GMSYS and gOcad.

## ACKNOWLEDGEMENTS

This research has been supported by the ProMine project within the VII Framework Program for research (NMP-2008-4.0-5, contract 228559). We acknowledge to EMED-TARTESSUS Company for facilitating the access to Río Tinto Mine.

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## 3D MODELLING OF SANTA OLALLA DE CALA AREA. NEW INSIGHTS INTO THE CALA REGION

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**KEY WORDS:** 3D modelling, Ossa-Morena Zone, Variscan plutons, field mapping, potential field geophysical data, gOcad.

### INTRODUCTION

The Santa Olalla de Cala area is located in the southern segment of the Iberian Massif that forms the pre-Mesozoic basement in most of the Iberian Peninsula and constitutes the westernmost extent of the European Variscan orogeny. More precisely, it is situated in the south-western limb of the Monesterio Antiform, within the Ossa-Morena Zone (OMZ), which exposes a polyphase and poly-orogenic record with a complex history. The current structure of the OMZ is mainly due to the Variscan orogeny. This study is focused in Variscan plutons that were emplaced in Late Proterozoic and Paleozoic sediments. Igneous and metamorphic activity of Variscan Orogeny led to the formation of various types of mineralization. In this paper two of these are included: the iron oxide replacement and skarn in the Cala mine and the Ni-(Cu-PGE) in mafic to ultramafic intrusion of Aguablanca Pluton

The aim of this work is to build a 3D model of Santa Olalla de Cala region. To achieve this, we have improved the previous geological mapping and have carried out a regional gravity survey. Then, we have constructed a 3D geological model, at regional scale, that includes these two previous mineralizations. The Cala mine model can be seen in Mediato et al. (this book).

### DATASET AND 3D GEOLOGICAL MODEL

For the area modelled, 30 units have been distinguished in the geological map: 15 are **metasedimentary** and 15 **plutonic**. These units have been used for constructing the geological cross-sections and geophysical modelling; however for 3D modelling some simplification is needed, so the units have been grouped and reduced in number. Eight plutonic units have been considered to correspond to some associations of the cartographic units distinguished: 1) Pre-Variscan granites; Santa Olalla Massif s.s. (SOM), which includes three units, 2) SOM/Migmatitic, 3)

SOM/Canteras & Común and 4) SOM/Sultana & Dioritoids); 5) the Aguablanca (Agb) pluton; 6) Cala (Cg), 7) Teuler (Tg), and 8) Helechoso (Hg) plutons. Except for the group of Pre-Variscan granites, they are considered as a single set of rocks constituting the so-called Santa Olalla de Cala plutonic complex (SOC) (García-Lobón et al. 2015).

The metasedimentary units have been grouped and reduced to only 4 for the 3D model. From bottom to top they are: 1) the Serie Negra Formation; 2) the Cambrian metasediments and volcanics; 3) the Lower Cambrian Carbonate Detrital Group (DCG), separated because it is a good reference level in the area; 4) other Paleozoic metasediments.

The **3D model** is c. 400 km<sup>2</sup> and illustrates the surrounding geology in depth of two outstanding ore bodies of the Spanish OMZ: Aguablanca (Ni-Cu) and Cala (Fe-Cu). The purpose of the modelling was to establish a structural framework encompassing the host rocks of both mines, which in turn will contribute to a better understanding of ore genesis and emplacement, and ore predictivity.

We have improved the previous **geological map** (Quesada & Sánchez-García 2002), being used as the starting point for the geological cross-sections and 3D model building. Several kinds of data have been used in this study (Figure 1A).

**Topographic data** has been imported as points from a digital elevation model of 100x100m cell size, provided by Instituto Geográfico Nacional.

We have analysed and interpreted **magnetic** and **radiometric** airborne data together with **gravity** and **petrophysical** data from the IGME databases, as well as newly acquired gravity and petrophysical data specifically for this work, totalizing 490 gravity stations and 414 petrophysical samples.

Twenty geological cross-sections (Fig. 1B) have been performed, crossing the main structures and taking into account the surface geology and radiometric maps. Depth estimations for the plutonic units were taken from literature.

A 3D model has been built in gOcad, integrating the above mentioned data (map data and cross sections) along with **mine plans** and **boreholes**, from which the ore bodies have been reconstructed. The model includes the eight intrusive bodies, two of them related to the mineral masses.

The **faults** have been digitized from its trace on the geological map and extrapolated downwards taking into account their dips and their cross cutting relationships. The **horizons** and pluton surfaces have been created by interpolation of the lines drawn on the cross sections using the DSI (Discrete Smooth Interpolator) and establishing constraints to those lines (Figure 1B). Local edition has been necessary where some conflict has been detected, especially in reverse faults zones. Horizons and plutons have been cut by faults and constraints in faults borders have been established in order to recreate the fault slips. The main issue has been to reproduce the temporal relationships

between the different intrusions, given that they are almost simultaneous.

A set of nine parallel geological cross-sections across the relevant structures have been modelled (with the corresponding petrophysical properties) and fit by **forward modelling** (see García-Lobón et al. 2015 for more detail). For this task we have used the latest GM-SYS software (by Geosoft). The observed anomalies were fit mainly by changes in the geometry of the different lithologies. In some cases, the changes were significant.

The initial model is fit with the magnetic and gravimetric data, rendering an improved model (Figure 1B), whose main difference is the reduction in volume and shape of the plutons, revealing a laccolithic appearance with rooting zones, some of them related to faults. However, no significant changes in the metasedimentary units were observed. The final model can be seen in Figure 1C.

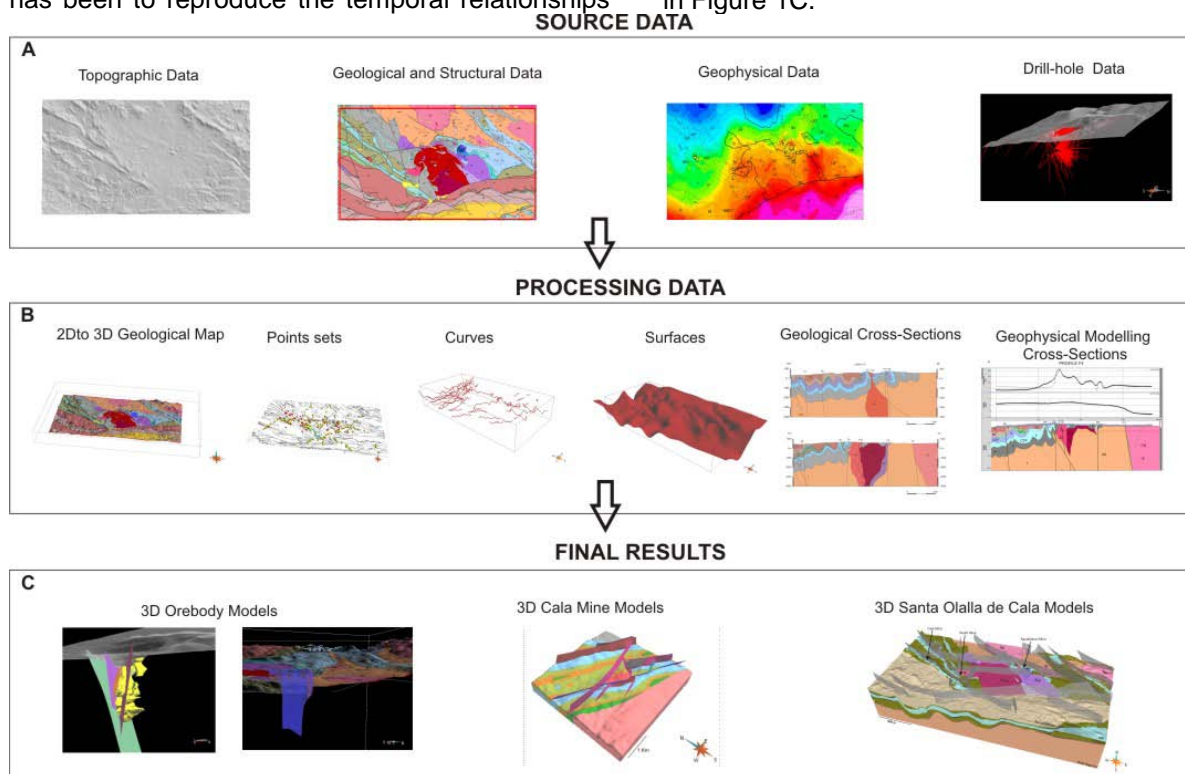


Figure 1 – Schematic flow-chart for the 3D modelling procedure through data integration between GIS, GMSYS and gOcad.

## ACKNOWLEDGEMENTS

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## COMBINED USE OF CROSS-SECTIONS, SEISMIC AND CORE DATA TO ASSESS CO<sub>2</sub> STORAGE CAPACITY AND SEAL GEOMETRY IN A TRIANGLE ZONE OF DEFORMATION: THE MC-J1 PROSPECT (CANTABRIAN MARGIN, SPAIN)

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**KEY WORDS:** Cantabrian Margin, CO<sub>2</sub> storage, 3D reconstruction, triangle zone, saline tectonics

### INTRODUCTION

The ALGECO2 project is a research initiative to characterize potential carbon storage reservoirs in Spain. In this framework, three targets have been selected in the Cantabrian Margin where seismic surveys have been collected around former oil wells. In this contribution the reservoir drilled by the MC-J1 borehole, 1.5 km offshore of the Cantabrian coast is examined as a possible candidate (Fig. 1).

The MC-J1 borehole locates on an inverted Lower Cretaceous graben system, which is one of the south vergent basement-cored anticlines of the Nansa thrust and fold belt (Espina, 1997). As is defined here, the Nansa Domain constitutes the northern and western boundary of a detached salt tectonics province supporting a Lower Cretaceous rift cover, termed the Coastal Santander Block (BCS). A complex triangle zone of deformation connects both areas (García-Senz & Robador, 2009) whose correct interpretation is therefore critical to evaluate the seal geometry of the reservoir.

### METHODOLOGY

Serial cross-sections, seismic lines, stratigraphic log correlation data and dipmeter data are used to approach the 3D geometry of the reservoir and the seal that permits calculate rock volumes. Raster seismic profiles have been digitized with the IMAGE2SEGY script and the SEGYPAT package (MATLAB) and incorporated in KINGDOM Suite for their interpretation. Lithological and petrophysical analyses of well log information allow interpreting the permeability of the seal and the reservoir. Timelines were converted to depth using velocity data from the Sonic Log and Bulk Density Log and the Interval velocity data from multichannel seismic profiles. Key surfaces (top-Urgon and base-Urgon) and

rock volumes and CO<sub>2</sub> storage capacity are established by interpolation in GOCAD software.

Four geological cross-sections were constructed with MOVE software, linking contacts and faults in the 1:25.000 geological maps of Cantabria (<http://mapas.cantabria.es>) with the top-Urgon and base-Urgon seismic surfaces. Core data consists of 1393 dipmeter measures used for dip sequence analysis (SCAT technique).

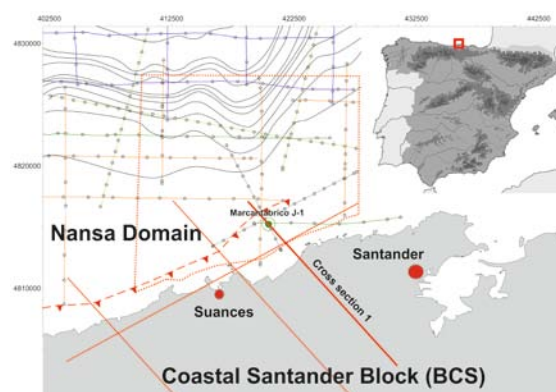


Figure 1 – Seismic lines and cross-sections around the MC- J1 oil well

### LATERAL AND TOP SEAL GEOMETRY

The MC-J1 trap is placed in a triangle zone of deformation. Their southern side is a cover frontal thrust that climbs up section from a detachment in Keuper salt into the pinch-out of the thin-skin Triassic-Lower Cretaceous basin, to terminate into the Upper Cretaceous-Paleogene. The imbricate thrusts nucleate in the limit with the viscous Keuper layer. Ramping in the cover is also favoured by the harpoon structure formed by graben inversion on the northern side of the triangle zone, which acts as a rigid indenter.

Potential lateral seal is provided by the thickened Keuper evaporites, whereas top seal is provided by the thick (>1000m) Upper Cretaceous to Cenozoic marly-limestones and marls that form the multilayered caprock. Seal integrity may be

affected nonetheless by deformation bands and fractures linked to the thrusts.

## RESERVOIR GEOMETRY AND CAPACITY

The reservoir is formed by 1607 meters of Aptian limestones and dolomites (the lower 600m may however correspond to Carboniferous dolomites) sandwiched between the Ordovician Q-arenites and the Upper Cretaceous marls (Fig. 1). The average density porosity calculated from Gamma Ray and Bulk Density logs analysis ranges between 0.1-13%.

Contour lines of the reservoir describe a dome structure with an arcuate E-W to NNE-SSW hinge line and abrupt periclinal ends which provide 4-

way dip closures. CO<sub>2</sub> storage capacities are shown in Table-1.

Rock volume (m <sup>3</sup> )	17054.90E+06
Porosity volume (m <sup>3</sup> )	308.260E+06
CO <sub>2</sub> storage capacity (tn)	231.195E+06
CO <sub>2</sub> efficient storage capacity (tn)	69.3590E+06

Table 1 – CO<sub>2</sub> Storage capacities in the Mar Cantabrico J-1 reservoir. The efficiency factor used here is the 30% of the CO<sub>2</sub> storage capacity.

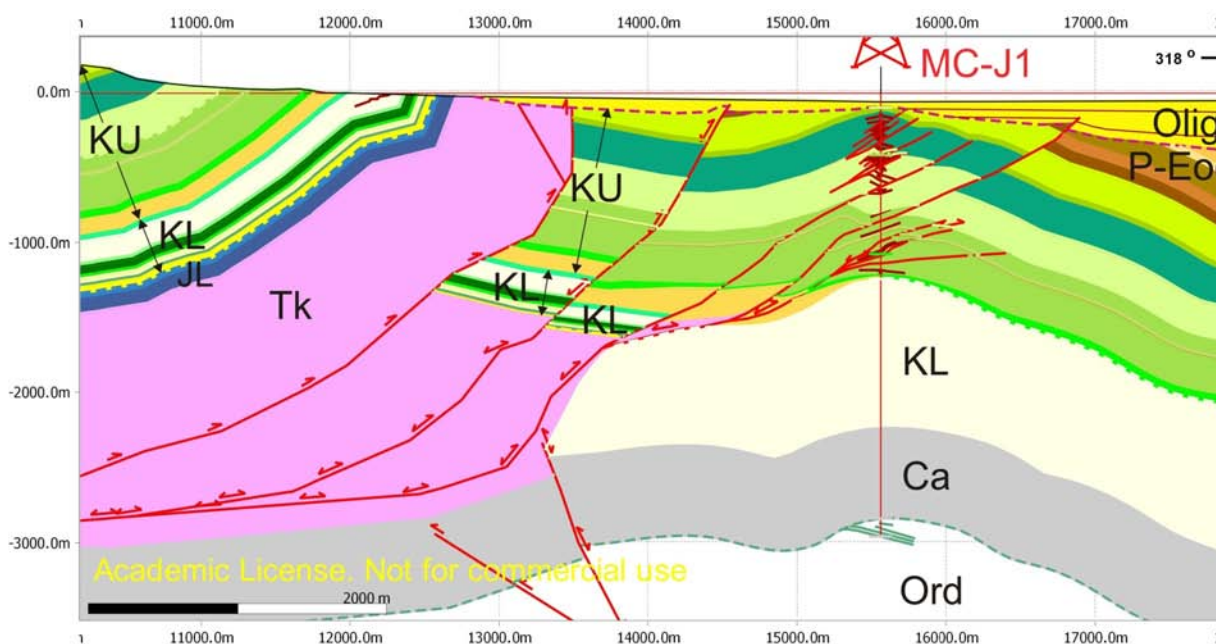


Figure 1 – Cross-section of the MC-J1 reservoir and trap in a triangle zone of deformation involving cover and basement thrusts. Ord: Ordovician; Ca: Carboniferous; Tk: Triassic Keuper; JL: Lower Jurassic; KL: Lower Cretaceous; KU: Upper Cretaceous; P-Eoc: Paleocene-Eocene; Olig: Oligocene. Move software

## CONCLUSIONS

The MC-J1 trap is as a complex triangle zone at the termination of a cover thrust sheet. The reservoir is a harpoon structure formed by the inversion of a Lower Cretaceous graben. Potential lateral seal is provided by a wall of Keuper evaporites and vertical seal is provided by a multilayered caprock affected by deformation bands and fractures. The available data indicates that the MC-J1 prospect is a suitable candidate site for geologic CO<sub>2</sub> storage with an efficient capacity of 69.3590E+06 tons.

## ACKNOWLEDGEMENTS

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## CROSS BORDER 3D MODELLING - CHALLENGES AND RESULTS OF A TRANSNATIONAL GEOTHERMAL PROJECT SASCHA GÖRNE <sup>(1)</sup>; OTTOMAR KRENTZ <sup>(2)</sup>

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**KEY WORDS:** 3D-modelling, geology, Saxony, Poland, geothermal energy, interoperability, database

- to establish a 3D geodata infrastructure using a 3D database
- to generate geothermal maps for several depths for interactive web-based use.

### TRANSGEOTHERM PROJECT

The TransGeoTherm is a common project of the Polish Geological Institute (PGI) and the Saxon Geological Survey (LfULG). It was co-financed by the European Union (EU) within the framework of the Operational Programme for Transboundary Cooperation Poland-Saxony 2007-2013. The project started in October 2012 and was completed in December 2014.

The realisation of TransGeoTherm is based on innovative methods analysing and interpreting geological, hydrogeological and geothermal data with respect to 3D modelling processed using the software package SKUA-GOCAD.

The main targets of the project are:

- to initiate and establish the use of low temperature geothermal energy as a low emission energy in the Saxon-Polish trans boundary region,
- to combine and process heterogeneous geoscientific data from both, the Polish and Saxon geological institutes,
- to perform a 3D subsurface model of the whole project area as source for 3D numerical simulations,

### DATA PREPARATION

As a first step all available geoscientific data was analysed and homogenised. After the evaluation of geological maps, printed reports and borehole documentations a set of 76 lithostratigraphic units was defined. Digital geological maps in different scales were used as constraints for the 3D model. Some problems occurred while combining these data with the high-resolution digital elevation model (DEM) as well after a coordinate transformation.

Information about subsurface geology was mainly obtained from 11.600 boreholes in the German part and only 1.250 boreholes in Poland, whereby most of the boreholes are not deeper than 50 meters. But about 500 boreholes up to 1.000 m deep allowed the prediction of the deeper geological structure. Besides this numerous digital map data, fault-lines and geological cross-sections were used as input data. The different scales, age and content of this data proved to be problematic.

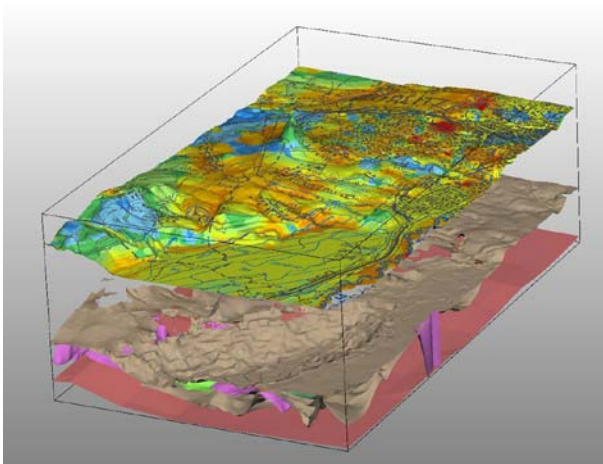


Figure 1 – cutout of the 3D model showing the geological horizons and the DEM color-coded with the thermal extraction capacity.

### 3D MODELLING USING GOCAD

The structural 3D subsurface model of the project area was created within the software Paradigm GOCAD. Since the investigation territory encompasses 650 km<sup>2</sup> the 3D modelling was performed by various team members in several sub areas. Therefore the project area was split in a western and an eastern region along the Saxon-Polish border, including a buffer zone covered by both areas.

Due to time limitations the Cenozoic and the Pre-Tertiary units were modelled separately. A consistent approach from bottom to top would have made fewer problems afterwards. Due to the

variety of stratigraphic units, modelling of the Quaternary was the most time-consuming step.

After processing all data within GOCAD, the results had to match the data-structure in the existing hydrogeological database. Therefore the triangulation of the surfaces was normalized by a so called master grid with a 25 m spacing. All attributes of the object are then stored cell-centred.

Furthermore, the regular grid was used to calculate the geothermal maps, showing the geothermal heat extraction in several depths.

The main modelling steps are:

- creation of horizon boundaries in 2D,
- construction of artificial constraints, honouring the locally measured layer thickness and the spatial distribution of borehole data,
- geostatistical interpolation of layer thickness and base heights,
- construction of the volume model based on base layers and layer thickness,
- conversion to a regular grid.

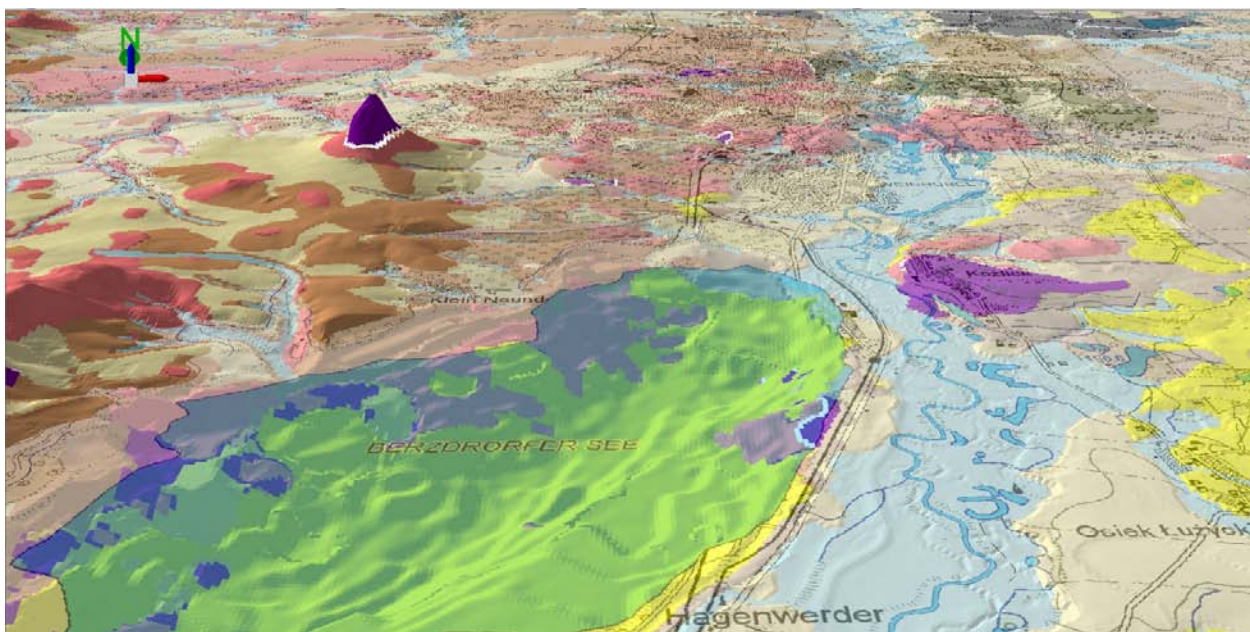


Figure 2 – final geological model of the Berzdorf region.

## CONCLUSION

Based on all available data a detailed three dimensional geological model was created within the binational TransGeoTherm project. Some problems and challenges occurred during the process of data preparation and modelling. Mostly a lack of interoperability of input data and data structures caused inhomogeneity in the intermediate results.

With help of a 3D database approach the final data could be stored consistently and made available for further projects. The derived information (3D model and geothermal maps) is issued via a public web portal.

## ACKNOWLEDGEMENTS

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Góra; TU Bergakademie Freiberg, Institute of Geophysics and Geoinformatics; SENCKENBERG Museum, Görlitz; Eugeniusz Idzik; Henryk Luchowski and Iwona Wołoszyn.

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## THE INTEGRATED DEEP GEODYNAMIC 3D MODEL OF THE PECHENGA DISTRICT (BALTIC SHIELD)

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**KEY WORDS:** *integrated 3D model, mantle, ore-forming system, SG-3*

The Pechenga ore district and its framework are among the most well-studied territories of the Baltic Shield. In addition to the detailed geological mapping, the Kola superdeep borehole (SG-3) was drilled, and a unique complex of deep seismic surveys were carried out there. Recently, the seismological data were correlated with results of

the various geophysical studies on the Barents Sea shelf plate.

The Pechenga ore district is an isolated segment of the Pechenga-Imandra-Varzuga the metallogenic zone. In the northeast district is bound by the Voron'nya-Kolmozersk fault, in the southeast - by the Litsk-Aragubsk fault, in the northwest - by the Inari-Kirkines fault system, and in the southwest - by a Pechenga-Varzuga system (Kazansky et al., 1994).

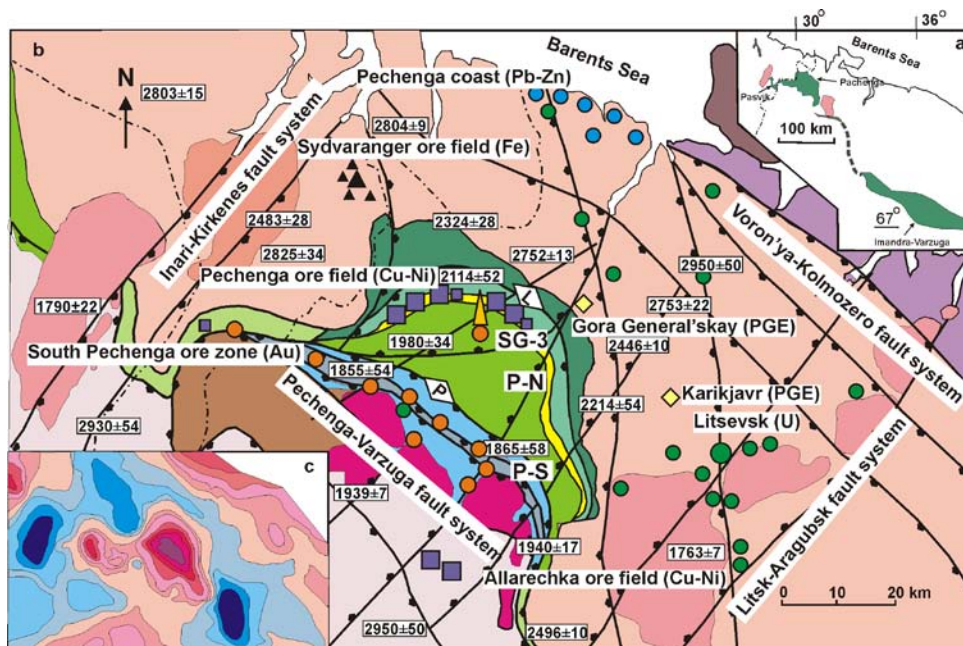


Figure 1. Geographic position (a), gravity field pattern (b) and schematic geological map (b) of the Pechenga ore district (Lobanov et al., 2010).

Within the suggested boundaries the Pechenga ore district, besides the Pechenga and Allarechka Cu-Ni ore fields, incorporates the Archaean banded iron ores of Sydvaranger, the Early Proterozoic PGE and Ni occurrences (Gora General'skaya, Karikjavr) the Late Archaean-Early Proterozoic U mineralization of different types (Litsevsk), the hydrothermal Pb-Zn veins of probable Riphean age, and enigmatic Au-Ag mineralization discovered at deep levels of the SG-3 borehole and surface in the South Pechenga structural zone (Fig. 1) (Lobanov, 2010).

Using data on the P- and S-wave propagation, a deep tomographic model of the Pechenga ore district with the SG-3 in its center was developed. It was found that the Earth's crust is separated there into upper heterogeneous and lower homogeneous layers, and a single-type inversion of S- and P-wave velocities occurs at depths of 8-12 km and continues to the southern part of the Barents Sea shelf plate.

Interpreting the data obtained by the Earthquake Converted Waves Method and deep seismic sounding, we determined the position and

relief of the Moho discontinuity beneath the Pechenga district. The Moho discontinuity lies at depths of 34–41 km. It is important that the smallest depth of the Moho discontinuity corresponds to the Pechenga structure and that the depth isolines outline the oval and elongated areas correlated with the general tectonic pattern of the Pechenga ore district, which evolved during the Karelian cycle from the riftogenic to postcollision stages (Fig. 2) (Kazansky et al., 2002).

In addition to the other geological data, this fact indicates that the Early Proterozoic metallogeny of the Pechenga ore district was determined by the mantle-crust interaction. During the Karelian cycle (2.4–1.7 Ga), the role of the mantle sources and processes gradually decreased, while the significance of the crustal phenomena increased. Consequently, the Ni-PGE mineralization of Mt. General'skaya was followed by the Cu-Ni deposits of the Pechenga ore field, and then, by U-bearing alkalic metasomatites (Litsk deposit). The combination of geological and seismic data allows us to correlate the Early Proterozoic metallogeny of the Pechenga district with the evolution of a mantle plume.

The analysis of the available seismic, geological, and petrophysical data provides the basis for distinguishing three types of first-order seismogeological boundaries: the base of the Earth's ancient continental crust, interface between the lower homogeneous and upper

heterogeneous layers of the crust, and interface between the Precambrian basement and unmetamorphosed Riphean rocks. All of these boundaries affect the metallogenic zoning of the Pechenga ore district. Seismogeological boundaries and are more important. The distribution of ore deposits of the Karelian cycle correlates with boundary, while the low-temperature hydrothermal polymetallic mineralization superimposed on the Karelian structures is generally confined to boundary.

The study of the SG-3 borehole section and samples from the surface indicates that the Archean complex within the interval of 8–11 km includes the metamorphic rock blocks with densities and seismic wave velocities similar to those of the outcropping rocks. These rocks compose the framework within which the later processes of retrograde metamorphism and fracturing were developed. We disprove the suggestion that the fluid-saturated zones of retrograde metamorphism can correspond to low-angle deep reflectors. We believe that the fluid-saturated low-angle seismic boundaries can be related to the latest zones of open fracturing, which continue from the Baltic Shield to the Barents Sea shelf plate.

The present research was executed under financial support of the Russian Foundation for Fundamental Research (project 14-05-00535).

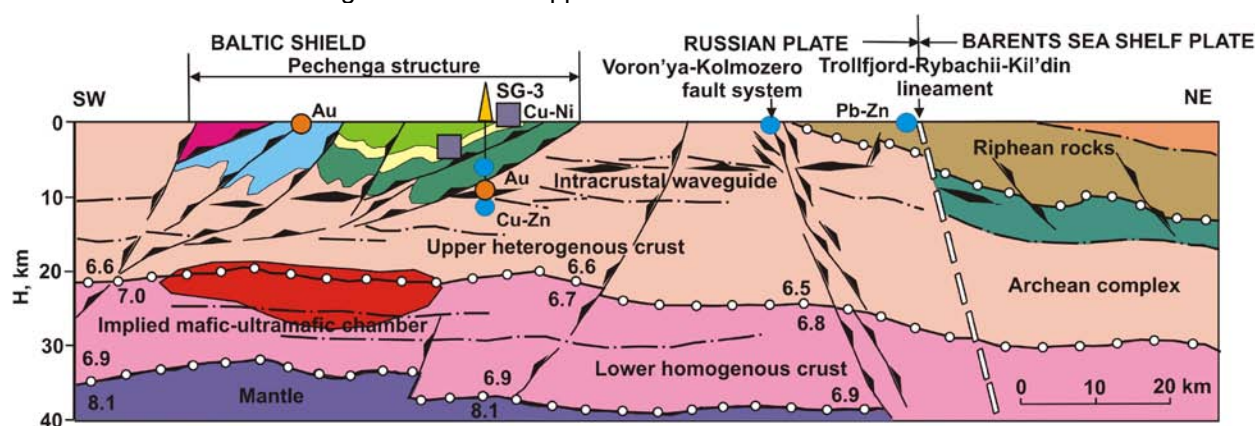


Figure 2. A section across the transition zone between the Baltic Shield and the Barents Sea shelf plate (Kazansky et al., 2002)

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## GROUNDWATER ASSESSMENT IN CARBONATE AQUIFERS FROM 3D GEOLOGICAL MODELS (ALICANTE, SE SPAIN).

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**KEY WORDS:** 3D Modelling, Carbonate Aquifers, Storage reserves, Alicante

### INTRODUCTION

The assessment of groundwater reserves in six of the main aquifers of the Alicante province was accomplished in the frame of an agreement between the Diputación Provincial of Alicante and the Geological and Mining Institute of Spain (IGME). The studied aquifers are:

- Carrascal-Ferrer.
- Mediodía
- Solana
- Cabo Roig – Campo de Cartagena
- Orqueta
- Serral-Salinas

We have built 3D geological models of these aquifers from geological and geophysical data to calculate the volume of groundwater reserves

below the piezometric level. The principal stratigraphic surfaces included in the 3D models are:

- Bottom of the Neogene Unit
- Bottom of the Upper Cretaceous Unit
- Bottom of the Lower Cretaceous Unit
- Top of the Triassic Unit

### METHODOLOGY

The methodology used for the groundwater reserves evaluation is constituted by two main elements:

1- The 3D geological model, constituted by the stratigraphic surfaces and faults that correspond to the boundaries of the aquifers. These models are built from geological (maps and structural data) and geophysical data (seismic surveys, electric and electromagnetic soundings and gravimetry) and wells.

2- The 3D grid model with the primary porosity data from field samples. The volume of groundwater reserves is calculated with the 3D grid and the piezometric surface.

The 3D software used for modelling was 3D Geomodeller and Gocad. The former is a software

Aquifers	Extension km <sup>2</sup>	Surface data			Subsurface data				
		Geol. maps	Porosity samples	Dips	Cross Sections	Seismic profiles	Gravity data	VES, TDES and MT	Wells
Carrascal	119	2	51	147	9	2			28
Mediodía	280	2		116	8	1			7
Solana	360	5	39	756	23	4	883	90	84
C.Roig	170	1			7	30			23
Orqueta	212	1			10	5			9
Serral-Salinas	268	2	44	373	10	6		94	38
TOTAL	1409	13	134	1392	67	48	883	184	189

Table 1 – Surface and subsurface data used for 3D modelling.

that builds complex 3D geological models (faults, folds, inverted bedding, intrusions, etc.), from geological maps, dips and sections with a cokriging geostatistical algorithm. The second been used to build 3D grids with primary porosity values in order to obtain the groundwater reserves volume.

Table 1 displays the amount of data used in each 3D model. An important compilation effort has been done from IGME and other databases. In addition, in some of the aquifers, new data like magnetoteluric soundings or structural data have been also acquired.

In order to improve the geological surface geometries, new 1392 dip data have been obtained from the intersection between the digital elevation model and the stratigraphic bedding. These data have been imported to 3D Geomodeller software.

Other important geophysical data used are the 2D seismic surveys for oil exploration. These seismic sections were originally scanned images of print sheets. Therefore they have been converted to segy format with the script Image2segy in Matlab software and imported to SMT Kingdom Suite seismic interpretation software. The interpreted time horizons converted to depth have been imported to 3D Geomodeller software.

In the Solana 3D model, gravity data were also used as an additional test to the model. A total of 883 gravity stations were processed to calculate the Bouguer anomaly. Then the 3D inversion was performed using 3D Geomodeller to fit the geometry of the contacts with the Bouguer anomaly.

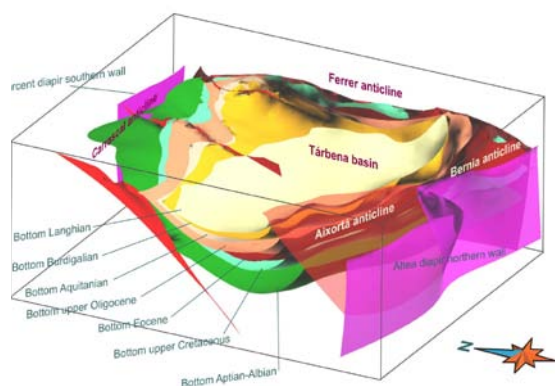


Figure 1 – Geological model of Carrascal-Ferrer Aquifer.

One hundred and thirty four samples were analysed to determine the porous system of the permeable rocks of each selected aquifer. We calculated the interconnected matrix porosity ( $p_0$ ) of the samples from core cubes to quantify storage. To avoid problems induced by core sampling, fresh samples without large vugs and

without fractures were selected. All the air was extracted from the sample and replaced by water.

We assume that almost all the storage capacity of the aquifer is located in the rock matrix. This feature is evident in detritic aquifers, and recently also accepted for carbonate ones [Ahr, 2008]. Thus, total storage capacity was obtained based on the determination of the saturated volume of the aquifer between the piezometric surface (at different heights) and the top and the bottom of each rock formation distinguished in the 3D model. The groundwater reserve curves, representing the storage volume of an aquifer below a given height, were then calculated for the 25th, the 75th percentiles and the mean of the field samples.

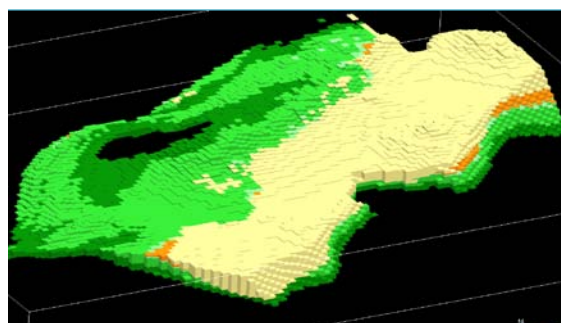


Figure 2 – Geological model of Serral-Salinas

## CONCLUSIONS

A methodological procedure for evaluating groundwater reserves in carbonate aquifers is proposed based on 3D geological modelling and the estimation of the matrix porosity. It was applied in 6 aquifers in the Alicante province (SE Spain) with a total extension of 1409 km<sup>2</sup>. This methodology is easily applicable to similar aquifers with low to moderate structural complexity, whenever a variety of geological and geophysical data are available.

The 3D models have provided values of total groundwater reserves. Subsequently, these geometrical models can be used to build flow and transport models that will allow water managers to obtain a better knowledge of each studied aquifer and to suggest the most favourable areas for groundwater exploitations in emergency situations.

## ACKNOWLEDGEMENTS

This project was founded by the Diputación Provincial of Alicante and IGME.

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## 3D GRAVITY INVERSION OF CALA MINE (OSSA-MORENA ZONE, SPAIN)

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**KEY WORDS:** Ossa Morena Zone, Cala Mine, cross-section, 3D geological model, 3D potential field inversion

stock (Cala granite). Cala granite is limited by an intrusive contact with the Cambrian Upper Detrital Formation (UDF) and a NW-SE thrust on top of the mineralized zone. The mineralization consists in layered and irregular shaped bodies of magnetite, separated from each other by skarn zones (Carriedo *et al.*, 2006).

### INTRODUCTION

The Cala Mine is located in the south-western limb of the Monesterio Antiform, within the Ossa-Morena Zone (OMZ) (Figure 1), next to a granitic

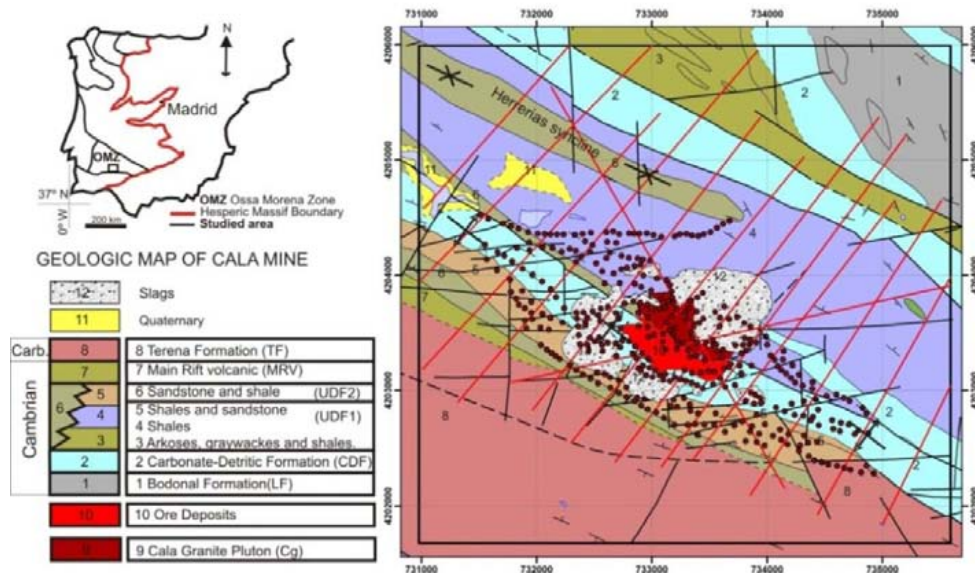


Figure 1 – Geological map with the location of the geological cross sections (red lines) used to build the model. Brown dots: location of the gravimetric measurements. Black rectangle: modeled area.

The aim of the work is to build a 3D model of Cala ore deposits to improve the knowledge of the geometry, physical properties and reserve estimation of the orebody from geological modelling and gravity inversion. To achieve this we have improved the previous geological mapping, we have constructed 14 geological cross sections and we have built a 3D geological model. Moreover, a gravity survey and sampling have been carried out to study the petrophysics of all geological units. The 3D geological modelling has been refined first by forward modelling and, finally, by 3D gravity inversion.

### MODELLED LITHOLOGIES

For the modelling, the lithology units of the geological map (Figure 1) have been grouped. From bottom to top: Bodonal Formation (LF);

Carbonate Detrital Formation (CDF), which hosts the mineralization; Upper Detrital Formation (UDF) divided into two series (UDF1 and UDF2); Main Rift Volcanic (MRV); Terena Fm; Ore bodies replacing the skarn rocks and showing a wedge-like geometry, thinning in depth (CDF\_Skarn-Orebody); and Cala granite (Cg). Densities are presented in Table 1.

Sampled units	Density (g/cm <sup>3</sup> )
LF	2.56
CDF	2.73
UDF1	2.58
UDF2	2.58
MRV	2.80
CDF_Skarn-Orebody	3.06
Terena Fm (TF)	2.56
CALA pluton (Cg)	2.66

Table 1 Densities of the 3D Cala mine model.

### 3D GRAVITY MODELLING

Once build up the initial geological model, its gravimetric response by forward modelling was calculated. The calculated residual anomaly presents values ranging between -3 and 3.08 mGal (Figure 2B). The main difference from the observed residual (Figure 2A) is the absence of the NW-SE positive gradient and the strong positive anomalies due to the CDF and MRV units. After minor changes in the initial model and once

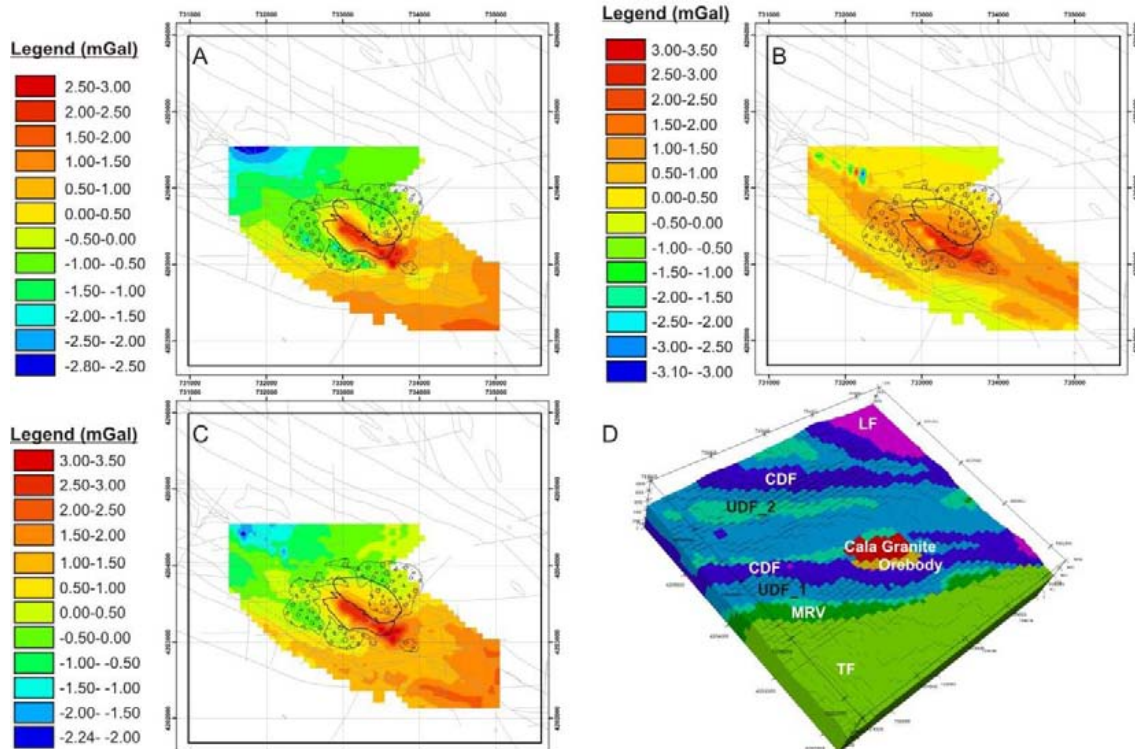


Figure 2 – A) Observed residual Bouguer anomaly; B) Calculated residual Bouguer from forward modelling; C) Calculated residual anomaly from the inversion (D)3D inversion.

The range of the calculated anomalies derived from the inversion is -2.24-3.48 mGal (Figure 2C). The pattern of these anomalies (direction, intensity and range) is very similar to the observed ones. The mineralization is well delimited by the central maximum and the shape of the positive NW-SE gradient together with the NE-SW interruptions of the anomaly, corresponding to the faulting.

In the geological model obtained from the inversion (Figure 2D) the mineralization geometry keeps its bottom at c. 200 m at the central and SE zones whereas to the NW becomes shallower than in the starting model. To the NW, the MRV completely disappears within unit 4; thickness of UDF2 decreases whereas thickness of UDF1 increases and the CDF units appears to be deeper.

The average variation for the densities is very small, 0.02 g/cm<sup>3</sup> with a SD of 0.1 g/cm<sup>3</sup>. In the mineralization zone, the density after the inversion has increased by 0.4 g/cm<sup>3</sup>, resulting in a calculated density for the ore bodies of 3.48

the pattern of the calculated anomalies were close to the observed anomalies, we have proceeded with the stochastic inversion.

The calculations were set for 100000 iterations, allowing small variations in the densities and more variation in the lithostratigraphic interfaces. The RMS of the results varies from 0.97 mGal at the beginning of the calculations to 0.27 mGal at the last iteration.

g/cm<sup>3</sup>. In the SE area, the results show a general increase in the UDF and CDF formations between 0.1 and 0.3 g/cm<sup>3</sup>.

As a conclusion, the results of the inversion show an increase in density of the CDF and the UDF1 towards the SE and in the density of the ore body which suggests the possible occurrence of new deposits.

### ACKNOWLEDGEMENTS

This research has been supported by the ProMine project "Nano-particle products from new mineral resources in Europe" within the VII Framework Programme for research (NMP-2008-4.0-5, contract 228559).

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## GEOLOGICAL MODELLING OF THE LOPÍN CO<sub>2</sub> STORAGE SITE, SPAIN

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**KEY WORDS:** *reservoir characterization, reflection seismic, boreholes, 3D geological modelling, CO<sub>2</sub> storage*

### INTRODUCTION

The IGME (Geological and Mining Institute of Spain) is currently developing a program of Subsurface Geology and CO<sub>2</sub> Geological Storage site screening and characterization. The aim of the program is to increase the knowledge of the subsurface structure of the country and to select and characterize a number of suitable areas for CO<sub>2</sub> storage. In the first phase of the program (ALGECO2) 70 areas were chosen and studied. Contour maps of potential storage formations were built from geological cross-sections and seismic lines (García Lobón et al., 2011). In this phase the Lopín structure was selected and studied obtaining

contour maps for the Buntsandstein formation (IGME, 2010). Currently, the IGME is developing the second phase of the program. The Lopín structure has been selected to be revisited because its proximity to a significant CO<sub>2</sub> emission centre.

The aim of this work is to better characterize of the Lopín CO<sub>2</sub> storage site, using all available seismic profile and well-log data. The final goal is to integrate all information in a 3D structural model of the Lopín subsurface, including the geometry and detailed distribution of the main geological units and faults, as derived from a throughout seismic interpretation. This model will provide new structural and stratigraphic knowledge of the Lopín structure within its regional geodynamic frame.

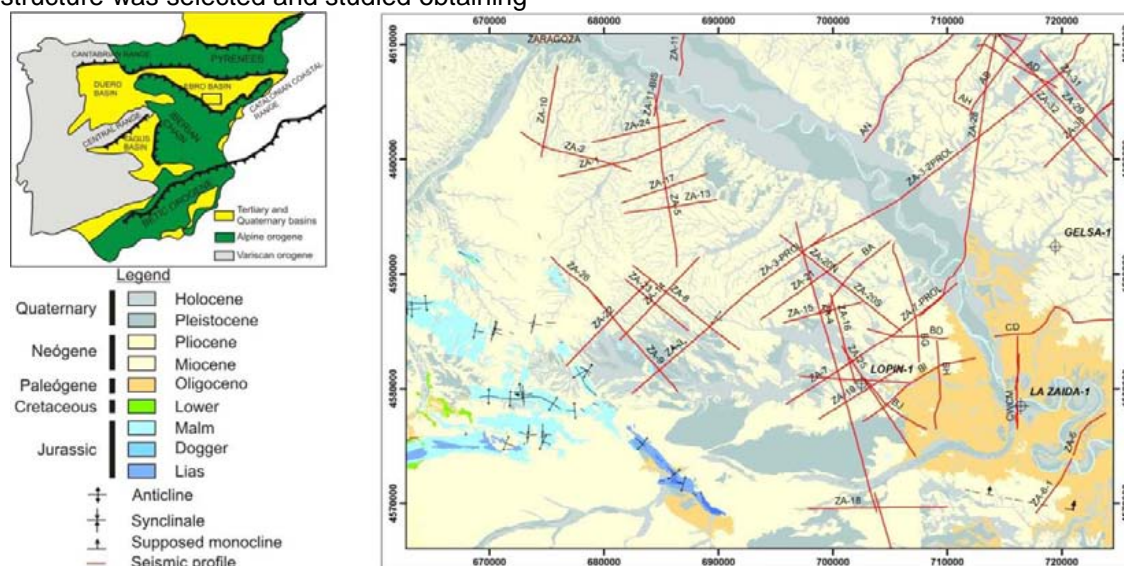


Figure 1 – Schematic geological map of the Lopín area.

### GEOLOGICAL SETTING

The Lopín structure is located in the Ebro Tertiary Basin in the transition between this domain and the northern part of the Aragonian branch in the Iberian Range (Figure 1). The structure is unconformably overlain by subhorizontal Neogene materials. At the southern part of the studied area Jurassic and Paleocene units crop out in the Belchite anticline.

Stratigraphically (Figure 2A), the Mesozoic succession starts with Triassic clastic sediments (Buntsandstein facies) overlying the Palaeozoic basement. On top of these materials, middle-upper Triassic dolomites, evaporites and marls

(Muschelkalk and Keuper facies) were deposited. The Jurassic series is constituted by a sequence of shallow marine carbonate and hemipelagic ramp sediments which are unconformably overlain by clastic series of Early Cretaceous ages.

The analysis of seismic sequences shows that Cenozoic rocks (Paleocene and Neogene) unconformably overlies the Cretaceous and Jurassic units (Cortés-Gracia, 2004).

### GEOLOGICAL MODELLING

Seismic interpretation was done in GEOGRAPHIX (© LMKR) and the 3D structural modelling was obtained with gOcad (© Paradigm).

The modelling process consists of creating horizons and faults, contours maps, upscaling well data, and layering, in order to generate a grid. Finally, a 3D model is created from the surfaces for the reservoir volume estimation.

Seismic surveys from the 70s were reinterpreted (Figure 1), taking into account the Lopín, La Zaida and Gelsa well data together with the surface information (geological map).

In the seismic interpretation we distinguished eight horizons, although only six of them have been considered to build surfaces for the 3D model of the Lopín structure: Buntsandstein Top, Muschelkalk II Top, Muschelkalk III Top, Keuper Top, Lias Top and Cenozoic Bottom (Figure 2A).

The reservoir and seal formations were selected following available information; porosity, salinity and depth data, from well logs. These formations are Triassic in age and in the Lopín area are affected by a NW-SE-trending anticline several tenths of kilometres long (Figure 2B and 2C). Alpine deformation involving the Variscan basement and Mesozoic cover consists of NW-SE

and NNW-SSE-striking reverse faults, subparallel to dominant structures in the Iberian Chain.

Two target reservoirs were considered (Figure 2D): Buntsandstein and Muschelkalk (MIII) facies. The available seismic data indicate that the Buntsandstein facies top is at approximately 1000 m depth and hosts a deep saline aquifer. The target reservoir series include the Hoz del Gallo and Cañizar formations (Figure 2A) with average thickness of 150-200 m and 5% of porosity. The seal comprises the evaporite facies (MII) with an average thickness of 100 m. Additionally, the Muschelkalk (MIII) facies are suitable as reservoir, they are located at 825 m depth with a thickness of 100 m and 2% porosity. The seal is formed by evaporites and marls of Keuper facies with an average thickness of 350 m.

The volumes of structures were calculated based on the -1250 masl for the Buntsandstein top and -1125 masl for the MIII top deepest closed contour lines. The estimated volumes are 3300 Mm<sup>3</sup> and 6100 Mm<sup>3</sup>, respectively.

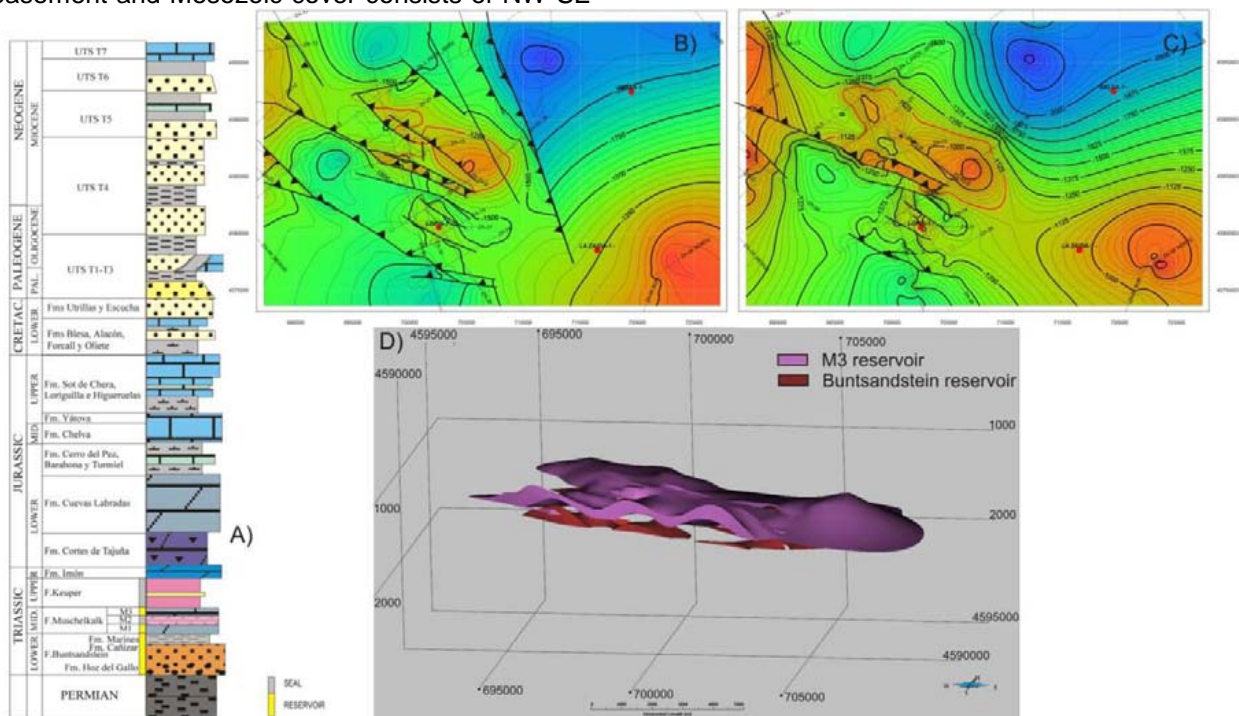


Figure 2 –A. Stratigraphic column. B. Depth (masl) contour lines of Buntsandstein top with spill-contour marked in red. C. Depth (masl) contour lines of Muschelkalk (M3) top with spill-contour marked in red. D. 3D visualization of the reservoirs.

## ACKNOWLEDGEMENTS

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## HYDROGEOLOGICAL WINDOWS MAP BASED ON 3D GEOLOGICAL MODEL

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**KEY WORDS:** *Hydrogeological window, geological 3d-modelling, contamination, filtration, GIS technologies.*

### INTRODUCTION

Map of hydrogeological windows for Moscow territory was developed in IEG RAS in 2012-13. A hydrogeological window is the area where contamination may quickly infiltrate from the earth surface and upper aquifers into deep aquifers. In Moscow, the middle carboniferous aquifer is a strategic water resource therefore it should be protected from pollution. Map of hydrogeological windows is accepted by ecology department of Moscow municipality and is used for rational nature management.

### MAPPING PROCEDURE

Geological conditions in Moscow are highly heterogeneous because of multiple paleovalleys in Jurassic and carboniferous deposits, filled with Quaternary sands and loams. At the most part of Moscow there exists the regional aquitard of Jurassic clays of the Callovian-Oxford age. Carboniferous deposits in Moscow contain of interbedded clay and carbonate, mainly limestone, layers.

Hydrogeological conditions in Moscow consist of multiple aquifers and active water interchange between them.

The main zoning parameter for mapping is the time of filtration from upper over-Jurassic aquifer to the middle Carboniferous aquifer. Quaternary aquitards including moraine loams and clays are not solid and cannot provide an effective protection for carboniferous aquifers. Only Jurassic and Carboniferous aquitards are

considered in the mapping procedure which consists of the following steps:

1. Geological zoning with the aquifer interchange type.
2. 3d-modelling to get aquitards' thicknesses.
3. Computation of the filtration times.
4. Zoning according the filtration time.
5. Mapping of potential hydrogeological windows based on structural-geodynamical and geomorphologic factors.

6 ranges of hydrogeological windows are established for the filtration time  $t$  (in years). Thresholds are selected according typical times of degradation of various contaminants and water supply exploitation periods:

- Range 1 ( $t < 1$ ) – the most dangerous area where any pollution may go directly to the strategic aquifer.
- Range 2 ( $1 < t < 3$ ) – typical pathogen microorganisms die within a year.
- Range 3 ( $3 < t < 15$ ) – 3 year is the half-life period of petroleum products.
- Range 4 ( $15 < t < 25$ ) – projected service life of water supply station.
- Range 5 ( $25 < t < 50$ ) – fact service life of water supply station.
- Range 6 ( $50 < t < 100$ ) – typical sorbtion time of heavy metals and radionuclids.

The full descriptions of the method see in (Pozdnyakova et al, 2015).

### GIS TECHNOLOGIES FOR MAPPING

Mapping of hydrogeological windows uses software and databases which have been developed in the project of large-scale geological mapping of Moscow (Osipov, 2015).

Following source data were used for the computation of the time of vertical filtration from the upper aquifers to the middle carbon aquifer:

- Heads of all aquifers (taken from the hydrogeological map of Moscow).
- Areal of low-permeable deposits of Jurassic and Carboniferous age (taken from geological maps of pre-Quaternary and Carboniferous deposits and actualized according the 3d model).
- Thicknesses of low-permeable deposits of Jurassic and Carboniferous age (are computed in the 3d model).
- Coefficients of vertical filtration of low-permeable deposits of Jurassic and Carboniferous age (are computed as expert estimation depending on thicknesses of deposits and geomorphological and structural-dynamical conditions).

Times of filtration are computed with raster arithmetic GIS tools.

The main differences from the traditional GSI3d technologies are following:

- Borehole database is integrated with mapping tools for maps and cross-sections design (see fig. 1). Data may be modified in any part of the triplet "Boreholes-Maps-Cross-sections" and then automatically displayed and corrected in another parts.
- Not only cross-section data are used for interpolation but borehole data too.

List of geological elements of the model includes Quaternary (as a whole), Cretaceous (as a whole), 3 layers of Jurassic, and 9 layers of Carboniferous deposits.

267 geological cross-sections (total length is more than 2010 km) were designed.

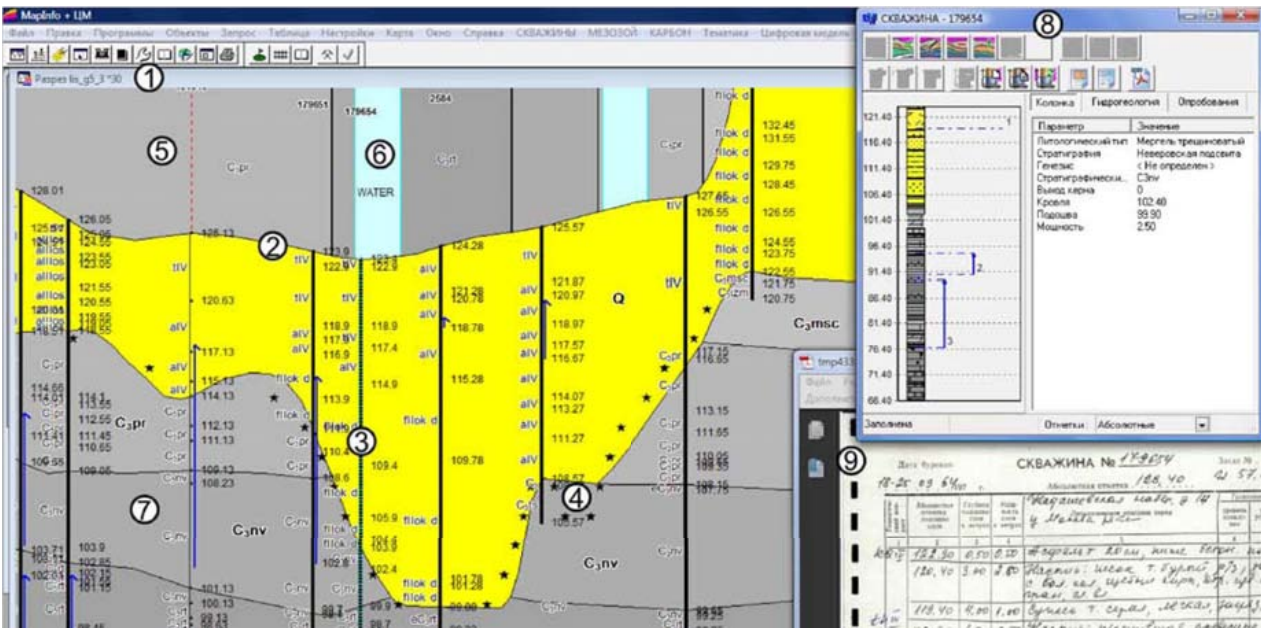


Figure 1 – Screenshot of geological cross-section design. 1 – Cross-section window; 2 – the earth surface; 3 – the selected borehole; 4 – traces of isohypses of the roof of pre-Quaternary deposits; 5 – traces of geological map' zones; 6 – trace of a river from the topography map; 7 – design of cross-section layers; 8 – borehole data editing window; 9 – borehole log window

Methodology of 3d modeling is analogous to the GSI3d method (Mathers & al., 2009): data from geological cross-sections supplement borehole data to make an adequate interpolation of roof

The project database contains archive documents and digitized data for more than 93000 boreholes drilled since year 1907. More than 15000 deep boreholes are included into the 3d

model. About 3000 boreholes are used for cross-sections design.

No data from geological archive may be used in the modelling without previous analysis and inspection. Very often data should be not simply recorded according nowadays conceptions but seriously re-interpreted. Our technologies admit us to see all the consequences of the new interpretation. During the modelling process about 1500 boreholes data were fixed or re-interpreted.

The technology scheme of 3d geological modelling of Moscow provides permanent actualization of the model as new information becomes available.

The 3d model may be exploited for other tasks, for example, traditional geological mapping, hazard mapping, and analysis of geological conditions for new city infrastructure objects such as underground railways etc.

#### ACKNOWLEDGEMENTS

We are grateful to all our colleagues who took part in the works on the hydrogeological window map.

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## 3D TEMPERATURE MODEL OF THE CENTRAL PO PLAIN (ITALY) : SUBSURFACE GEOPOTENTIALS

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**KEY WORDS:** *temperature, 3D modelling, geopotentials*

and requires borehole radius. It was applied to correct 43 BHT values from 12 wells..

### ABSTRACT

In this study we present the results of GeoMol project (Alpine Space 2007-2013 Program) concerning 3D temperature model in the Italian pilot area. The Italian pilot area is located in the Po Valley and in particular in a portion of the territory of the Lombardy and Emilia-Romagna region; it includes a portion of the Alpine and Apennines foreland basins (fig.1).

The first step was the conceptual design for 3D-modelling workflows in the project area.

The first part of the workflow is about the implementation of 3D temperature model by selecting, preparing and processing the existing temperature data of hydrocarbon wells. In particular 127 values of BHT from 34 hydrocarbons wells have been analyzed for the development of temperature model. The sources of data were hydrocarbons wells profile, Italian database of geothermal data and a collection of temperature data provided by oil companies. Two different methods of BHT correction have been used: Horner method, where it was possible (2 or more BHT at same depth, same circulation time and different time after stop circulaton), for 17 wells and 66 BHT. Where temperature-time series for 2 or more BHT at same depth were not available, the Zschocke method (Zschocke, 2005) has been used, which can correct a single BHT

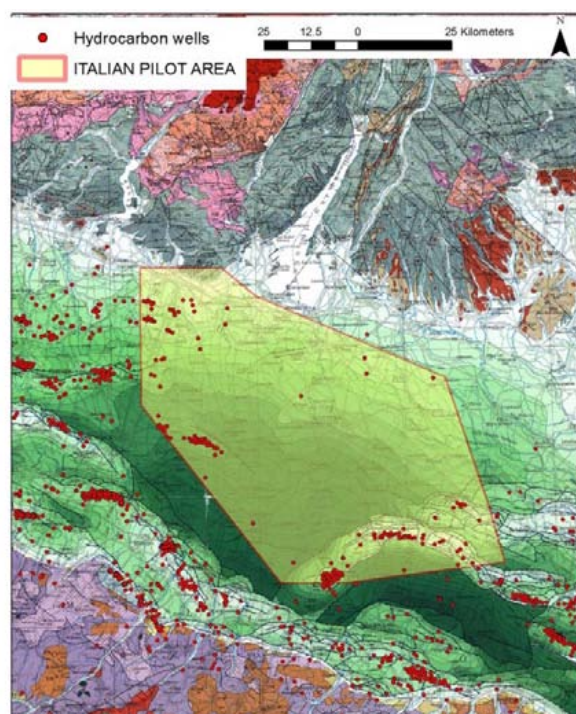


Figure 1 – Italian Pilot Area.

In the second part of the the workflow, given the geological and structural framework of the study area, the geothermal gradient domain has

been divided in three different geothermal gradients; the limits of these gradients are geological horizons mapped from seismic sections analysis and modelled in the 3D Geology Model elaborated by ISPRA (Maesano, D'Ambrogi, Ferri & the Italian GeoMol Team, this volume; Maesano & the Italian GeoMol Team, 2014). First gradient, named K0, from ground level to base Quaternary. Second gradient, named K1, from base quaternary to top giurassic-cretaceous carbonatic succession and the third gradient, named K2, for the carbonatic succession. The three gradients were interpolated over the whole study area using a geostatistical tool in ArcGis (IDW), so three different grids relating to K0, K1, K2 have been created and the relative shape files were extracted.

An excel file with all X Y points of the area and their respective values of K0, K1, K2 was linked to Z data (depth) from 3D Geology Model from software MOVE. Points extracted from the grids were intersected with the geological horizons in depth (z), so another Excel file which allows the calculation of geothermal outputs was developed. Some areas had particular problems, so they were calculated separately with a clip and merged in the total file through a query.

The main output of the model are maps with the cuts of temperature in depth and the relative geothermal occupancy, isotherms maps, top formation temperature maps and relative geothermal occupancy.

Through the software Leapfrog Hydro has been created a final 3D temperature model; the main goal was to populate a 3D geological model with temperature data. The grid and shape files of temperature (T) and depth (Z) data was downloaded in Leapfrog and the final 3D model has allowed us to harmonize and populate the whole 3D geological domain analyzed in the pilot area.

The final product of the Project are an example of the fruitful collaboration between Geological Surveys, Research Institutes and industrial companies that produced a final output freely accessible to the public and can be used as the starting point for different type analysis in different fields.

## ACKNOWLEDGEMENTS

The project GeoMol integrates partners from Austria, France, Germany, Italy, Slovenia and Switzerland and runs from September 2012 to June 2015. The project is co-funded by the Alpine Space Programme [www.alpine-space.eu](http://www.alpine-space.eu) as part of the European Territorial Cooperation 2007-2013. For further information please refer to [www.geomol.eu](http://www.geomol.eu)

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## COMBINED SURFACE GEOLOGY AND WELL DATA: 3D UNDERSTANDING OF THICK EVAPORITE FORMATION IN THE EOCENE EBRO BASIN (MANRESA - ARTÉS AREA, CATALONIA, SPAIN).

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**KEY WORDS:** *Eocene, Ebro basin, evaporates. Cardona Formation, Artés Formation*

The obvious advantage of integrating geological data in 3D models is of particular interest in those examples that are used as reference study cases. The Ebro basin (extending NE of Iberian Peninsula, see figure 1) is a reference area to investigate the sedimentology and architecture of alluvial fans and related continental deposits, evaporite formation and associated salt tectonics etc. Our study aims to better constrain the formation of thick evaporite succession by combining surface geology with subsurface data compiled from public wells of different purposes (potash mining, hydrogeology and geotechnics).

The Tertiary Ebro basin was bounded by three alpine orogens: the Pyrenees, the Iberian Ranges and the Catalan Coastal Ranges to the N, SW and SE, respectively. This basin was connected with the Atlantic sea during most of the Eocene, but towards 36 Ma (Priabonian) it started to become continental (endorheic). During this process, a thick evaporite succession was accumulated at the end of marine sedimentation (see basin evolution in Puigdefàbregas et al., 1986). This evaporate accumulation is object of intensive potash mining and is also found in the Pyrenees (Navarre area).

The evaporite succession in the basin depocenter (Pueyo, 1975) is characterized by a succession of: basal anhydrite (some 10 m thick),

halite (around 200 m), mix of halite and silvite (potash, few meters), mix of halite and carnalite (some 50 m) and a transition member with halite, anhydrite and mudstones (exceeding 50 m). In contrast, in the basin margins the typical evaporite succession is a gypsum formation known as Òdena Fm. (see Ortí et al. 1984). It has around 20 meters of thickness and crop out in three main areas: Òdena, Vic and Artés. These gypsums have mainly been studied in the two first localities. The lateral relationships show how evaporate gypsum evolve to thinner stromatolitic layers (some 5m thick) to build up the so called 'terminal complex' (Travé et al. 1996). The lateral evolution (landwards) of this terminal complex has been reported in the Vic area, where the associated Sant Boi Fm. records brackish to freshwater floodplain environments (Sanjuan et al. 2012).

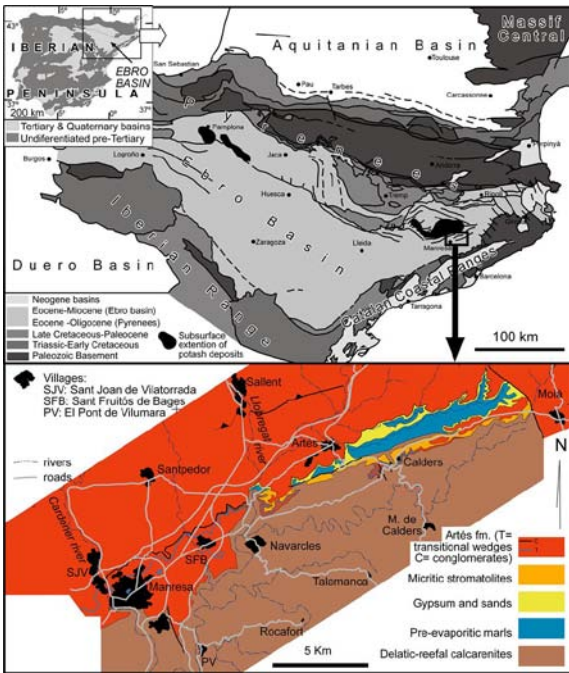


Figure 1 – Top: geological map of the Ebro basin (by J. Vergés). Bottom: summarized geological map of the study area.

Fieldwork for this study consisted in the mapping of several critical areas (from 1:5000 to 1:25.000 scales, summarized in figure 1) and the detailed measuring of 13 sections and one well. This geological dataset together with 4 public

potash exploration wells, were merged in the Petrel platform (Schlumberger). Afterwards, several surfaces were built (see a selected area in figure 2). Ongoing work is intended to understand the interaction of the four major distinctive features of the area: (1) the terminal complex is relatively close to the deep basin depocenter, (2) the Santa Maria group is partially replaced by the Lower Artés formation (López blanco et al., 1994), (3) an angular unconformity is observed within this succession, and (4) the lower Artés formation has several wedges of marine influence recording transitional settings and the effect of tidal currents. The occurrence of these wedges was first mapped by Larragan and Masachs (1956) but further surveys hardly considered them, despite some relevant outcrops exist, both natural and anthropic (road cuts urban ephemeral outcrops) in Manresa (Oms et al. 2012) and Sant Fruitós. The successful integration of these features in a 3D model will show they interact and will allow the characterization of an important episode in Ebro Basin evolution.

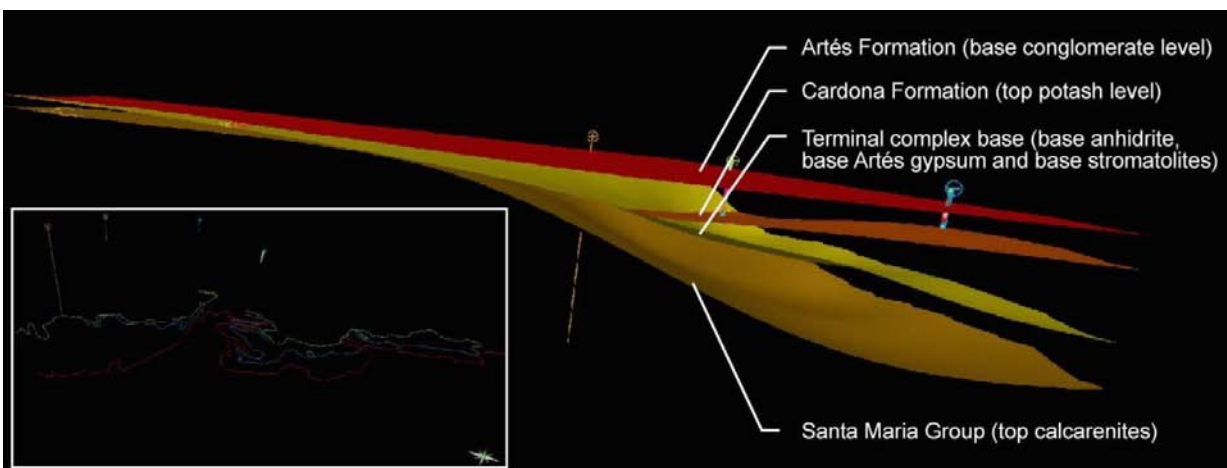


Figure 2 – In the small square are drawn the input data (mapping and public exploration wells). The big one presents a NW-SE cross-section of the area that permits to see the basin depocenter with evaporites to the NW.

## ACKNOWLEDGEMENTS

Schlumberger Ltd kindly provided the Petrel platform to develop this research.

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# THE AGER BASIN (EOCENE, PYRENEES, SPAIN): TIDAL INFLUENCED DELTAS 3D BUILDING

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**KEY WORDS:** *Southern Pyrenees Foreland Basin, Ager, deltas, Eocene*

## Introduction

The good exposure and accessibility of the Eocene outcrops around Àger village (Lleida, Catalonia, Spain) has permitted their study as field example of tidal influenced deltas in compressive settings.

The Àger basin is a part of a South Pyrenean Foreland Basin developed during the Upper Cretaceous and Paleogene. Montsec Thrust limits the basin to the north while Millà and San Mamet Anticlines to the Southwest and Southeast. To the East and to the West the Eocene is covered by Oligocene and Neogene post-tectonic conglomerates (Fig.1).

The Àger Basin record comprises different units from end-Cretaceous to Paleogene. This study is centred on the Lower Eocene unit known as Fígols Sequence by Mutti et al. (1985). This sequence comprises two tide-dominated deltas (Baronia and Ametlla Formations) separated by a marl level (Pasarel-la Formation). These clastic formations have been studied under a classical sedimentological point of view by several authors such as Lompart (1977), Mutti et al. (1985), Dryer and Fält (1993), Zamorano (1993) and Olariu et al. (2012).

The main goal of this work is to build a 3D mapping of the Àger Basin deltaic record. This attempt is centred on the upper delta (Ametlla Formation), which permits to study the spatial relations and interdigitation between the different muddy and sandy levels. Future works could allow reservoir simulations of tidally influenced deltas in compressive settings that. This could contribute to understand this kind of hydrocarbon reservoirs

## METHODOLOGY

The first step was to download the different geological maps with a resolution of 1:25000,

orthophotographs with a resolution of 1:25 and Digital Elevation Model (DEMs) with a resolution of 5 meters from the studied area. This information was obtained from the web of *Institut Cartogràfic i Geològic de Catalunya* ([www.icgc.cat](http://www.icgc.cat)). The information of the wells has been acquired from the web of *Instituto Geológico y Minero de España (IGME)*.

All of these maps were previously treated to adapt the files to “petrel-accepted” files.

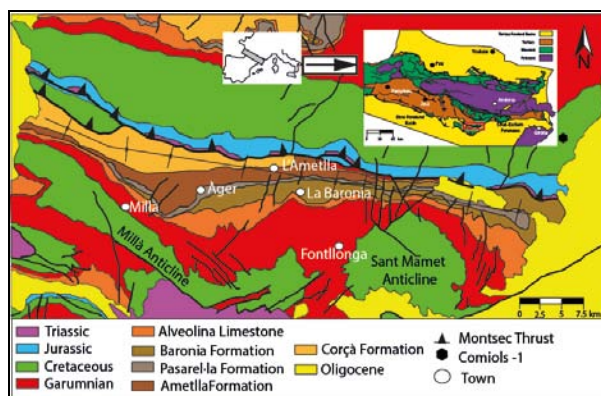


Figure 1 – Location of the Àger Basin

The 3D model has entirely been built with Petrel Schlumberger software.

The first stage was to draw the thrust bounded northern limit of the basin. This thrust is emplaced on top of the Eocene record. To the west and to the east, this thrust is covered by Oligocene conglomerates (Fig. 1). For this reason we used open access wells, seismic profiles and published (ICGC) geologic cross sections.

After drawing the Montsec, were used the geological maps to draw the base and top of Fígols Sequence, in other words, the top of Alveolina Limestone and the top of Ametlla formation.

After this delimitation, the next procedure was to make the detailed cartography, trying to differentiate the sandy and muddy levels of the deltas and trying to see the small-scale faults that could not be differentiated in geologic maps. This

allows to differentiate them between syn-sedimentary and diapirical-related faults.

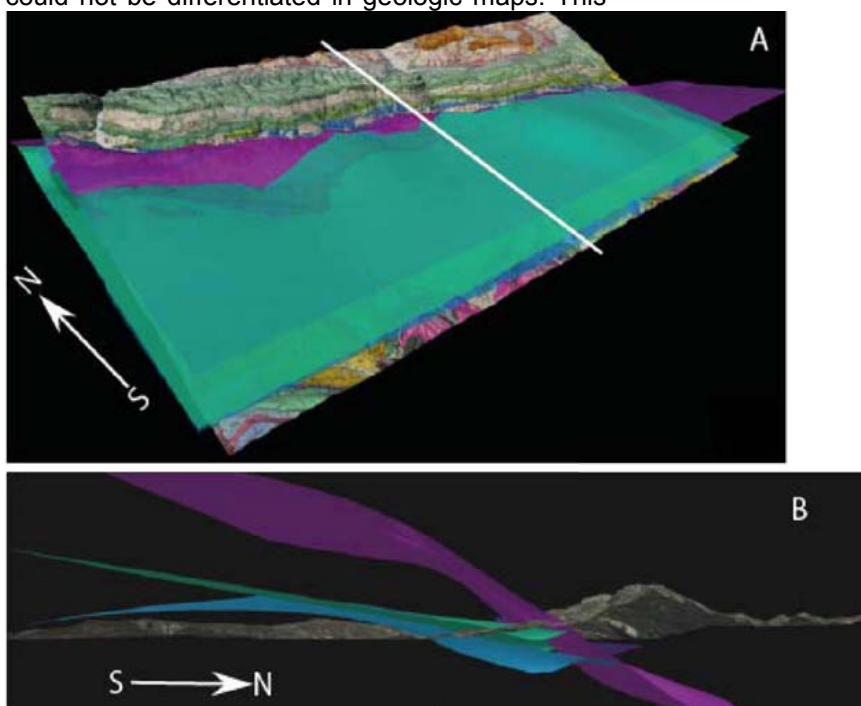


Figure 2 - Images of the model (from the Petrel software) displaying the main boundaries of the Fígols sequence. The base (blue) corresponds to the top of Alveolina Limestones and the top (green) is the upper limit of Ametlla Formation. The surface of the Montsec thrust is represented in purple. A: General view of the model from the top. The white line corresponds to the trace of cross section represented in B. B: Cross section and orthophotomap showing the relationships between the Montsec and Fígols Sequences.

## CONCLUSIONS

This model shows the potential of 3D data to improve geological studies. The model structure shows a development of small folds as a consequence of the Montsec thrust advance and distensives faults developed orthogonally to the thrust advance.

The future display of sandstone *versus* mudstone distribution of the delta systems, together with sedimentary facies, will provide a well-documented reservoir analogue for these environments (including tidal bars; barrier islands fluvial channels, etc.).

## ACKNOWLEDGEMENTS

Schlumberger Ltd kindly provided the Petrel software package through an agreement with the Geology Department of Universitat Autònoma de Barcelona. We also thank to M. Diviu for his assistance in the first steps with software using. Information from Geological Maps was obtained from IGCC, while seismic lines and an exploration well was obtained from IGME.

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# DIGITAL GEOLOGICAL MAP OF GREECE IN SCALE 1:1 000 000, HARMONIZED TO ONE GEOLOGY EUROPE

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**KEY WORDS:** *geology, digital map, GIS, harmonization, One Geology Europe, Greece, scale 1:1M.*

## GEOLOGICAL MAPPING IN GREECE

The Institute of Geology and Mineral Exploration of Greece (IGME) is the state's advisor on geoscientific and mining issues. One of its main activities is the geological mapping in various scales by surveying the country's geological structures (basic geological research). In nearly 65 years of its activity, IGME has produced a very large volume of geological maps (326 map sheets) covering geographically the whole Greek territory at a scale of 1:50000 (Photiades & Zervakou 2008; Zervakou et al. 2012). Those 326 analogical geological map sheets were digitized resulting in a digital database of vector geological data from the 1:50000 scale maps, in the form of an ESRI Personal Geodatabase (Zervakou et al. 2010). Moreover, the geological mapping across the country at a scale of 1:50000 is a dynamic project requiring continuous up-dating to support any developing activity, thus a second edition of many map sheets is now in progress.

## DATA HARMONIZATION

In 2013 IGME was invited to participate in the One Geology Europe Plus initiative, under the auspices of the EuroGeoSurveys, in order to provide a digital geological map in scale 1:1000000 (1:1M) harmonized across Europe. The purpose of the project was to compile fragmented geological data products from all over Europe and make them available through a single portal. The portal provides access to data and metadata held by each organisation based on standards developed in the One Geology Europe project and under a common licence; data products were compiled at a scale of 1:1M.

The first step towards the elaboration of the Digital Geological map of Greece in scale 1:1M was to identify the dataset to be used; for this purpose the vector geological data, from the 1:50000 scale maps, were chosen since this was the most reliable and up-to date information and the only in digital format.

The 1G-E vocabulary (Asch et al. 2013) describes the lithology, age and genesis of the rocks and the tectonic structures. The harmonization process of the IGME geological data involved two steps:

- Semantic harmonization of the “geological formations” and “tectonic lines” feature datasets, based on the One Geology Europe vocabularies (GeoSciML v2.1). It is noteworthy that the IGME database included 1796 codenames corresponding to different lithological formations/units while the One Geology Europe vocabulary for “lithology” comprised only 164 terms, thus a first step towards the 1:1M scale was accomplished in this way. An example of a harmonized map sheet is shown in Figure 1.

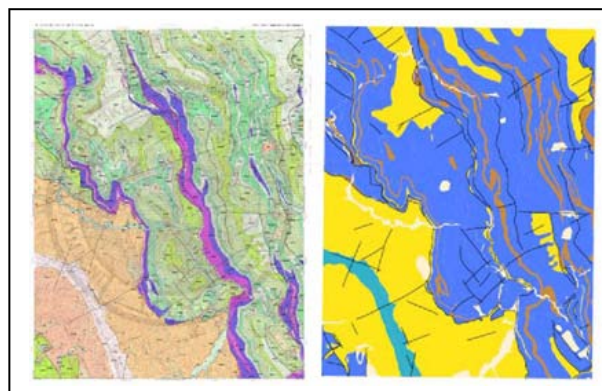


Figure 1 – Geological data semantic harmonization according to One Geology Europe Guidelines, the example of the Myrofyllon map sheet, scale 1:50000 with the original map (left) and the harmonized (right).

- A second issue that had to be dealt with was the heterogeneity, inconsistency and discontinuity of geological features between adjacent map sheets. These problems mostly reflect the different geological approaches and interpretations concerning the geology of the Hellenides, due to the fact that geological mapping in Greece has been implemented during different time periods by various geologists carrying different geological and geotectonic interpretations and based on various topographic backgrounds. Towards this scope, geometric harmonization of the “geological formations” and “tectonic lines” feature datasets was carried out – at a scale 1:1M, in terms of snapping/editing for minor mismatches and incorporation of new unpublished data from the forthcoming second edition map series.

## 1:1M DIGITAL MAP

Using the digital harmonized data described above the 1:1M digital geological map of Greece was compiled by means of step-by-step upscaling.

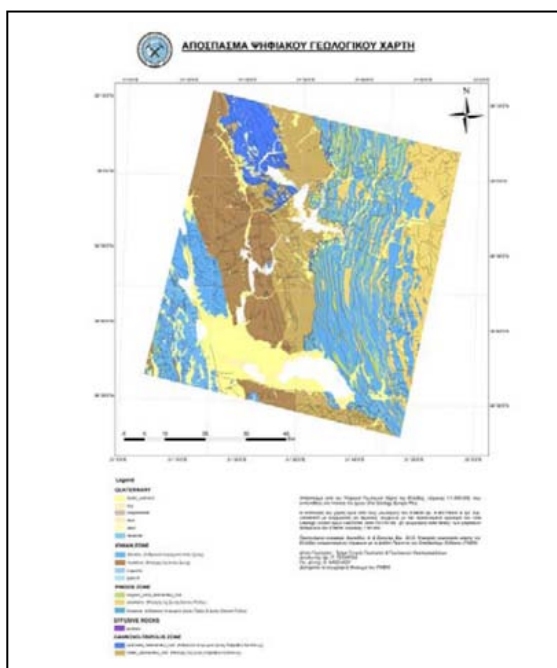


Figure 2 – Part of the digital geological map of Greece, depicting the different lithological attributes between adjacent geotectonic zones.

One important factor in terms of describing geological formations in Greece is the “tectonic unit” which incorporates information about the lithology, age and geotectonic zone, and as a result the tectono-stratigraphy of the examined geological formation, in conformity with the External and Internal Hellenides, the Rhodope and the Cyclades core complex systems. According to the One Geology Europe guidelines two separate layers are created corresponding to lithology (surface or bedrock) and age, and all additional information are given in terms of attributes in the feature dataset. To be able to provide a single map, harmonized to the given guidelines but also providing a direct distinction between geotectonic zones, different lithology terms from the GeoSciML vocabulary were associated with formations from different geotectonic units, e.g. the flysch formation of the Ionian zone is described as mudstone (primary lithology) while that of the Pindos zone is named sandstone (primary lithology). An example is presented in Figure 2. The final outcome of all the above was the first digital geological map of Greece in scale 1:1M, harmonized to One Geology Europe terms, and thus the international standards. The map comprises (a) the lithology layer, using a total of ~75 terms, with attributes providing information about age, genesis, accuracy etc., and an

additional column with the geotectonic zone as it is mentioned in the IGME map series, and (b) the lines layer to include all major tectonic structures.

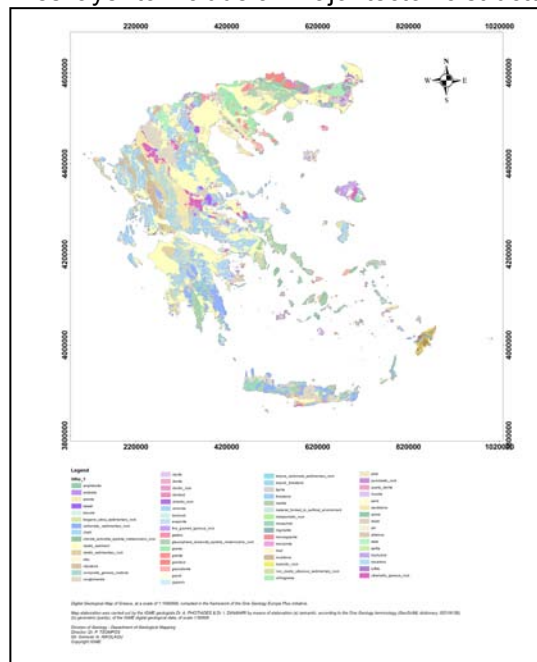


Figure 3 – Digital map of Greece in scale 1:1M.

## ACKNOWLEDGEMENTS

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# REGIONAL TECTONIC FRAMEWORK, STRUCTURE AND EVOLUTION OF THE ALAMEIN BASIN (WESTERN DESERT, EGYPT) – INFERENCES FROM 3D ONSHORE REFLECTION SEISMIC DATA

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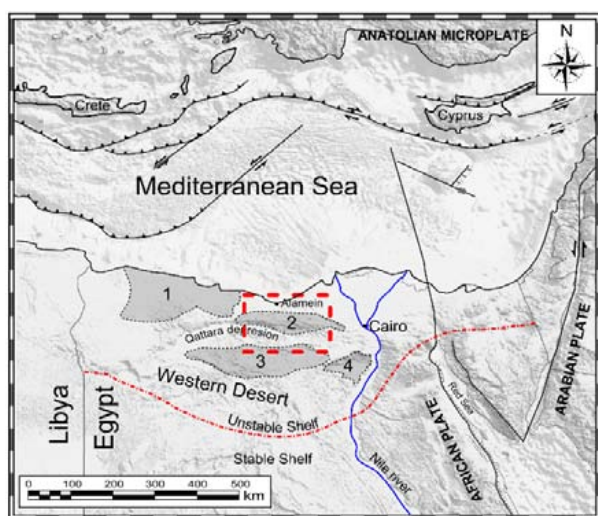
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**KEY WORDS:** *Alamein, Basin, transtension, rifting, 3D seismic, fault, enhancement.*

## INTRODUCTION

The Alamein Basin is part of the prolific oil Western Desert region (Egypt), originated during the Mesozoic rifting of Northern Africa, (fig.1). Its complex evolution was linked to Gondwana break-up and comprises several rifting stages (Jurassic to Cretaceous) followed by Neotethyan passive margin evolution and inversion during the Syrian



Arc deformation (Cenozoic).

*Figure 1 – Digital Elevation model SRTM 30 and 90 (by NASA) including the main geographic and tectonic features of the studied area. See the main sedimentary basins: 1: Matruh (1); Alamein (2), Abu Gharadig (3) and Gindi (4) basins.*

In addition, the development of the Alamein Basin was strongly influenced by the Atlantic Ocean opening during the Mesozoic (Meshref, 1990) and by the Red Sea and the Dead Sea transform fault system during the Cenozoic (El-Motaa & Kusky, 2003). In both cases these episodes resulted in several stages of transtensive deformation overimposed either to the rifting and the passive margin stages of the basin.

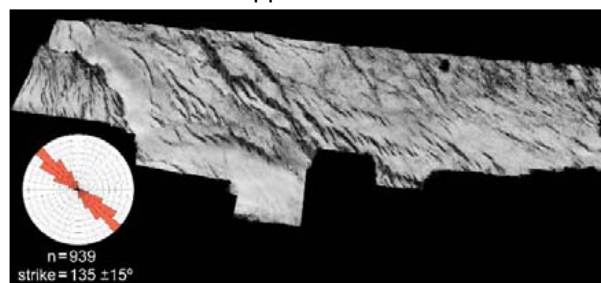
This study combines onshore 3D seismic and well data to evaluate the structural Mesozoic and Cenozoic evolution of the Alamein Basin and its relationship with the main regional-scale tectonic events.

## DATABASE AND METHODS

The available 3D seismic survey extends over 3750 km<sup>2</sup>. Several exploration wells were also available, which have been used to obtain back-stripped subsidence curves.

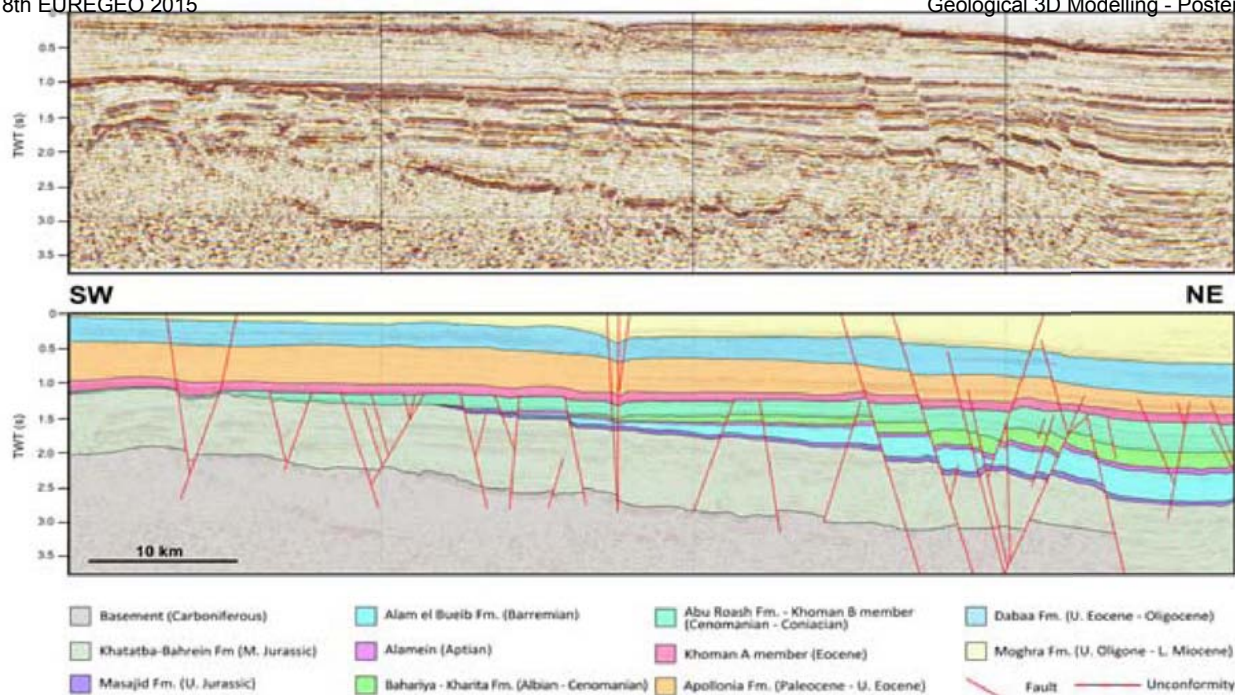
After a conventional interpretation of several 2D lines extracted from the bulk 3D volume, several time domain key horizons were mapped. These surfaces have been used to obtain thickness maps and display seismic attributes (Fig.2).

Seismic attributes consisted in fault enhancement following a workflow described by Medeiros and Antunes, 2013 based on the BG Fast Steering algorithm. The workflow consists in the creation of a steering, standard steering and background steering cube. Finally, a dip steered median filter to remove random noise and a structurally oriented filter to enhance faults have also been applied. The enhanced faults have been set as an attribute over the mapped horizons.



*Figure 2 –3D mapped horizon with the fault enhancement cube displayed as an attribute and fault measurement and projection into a rose diagram; this has been carried out in the main mapped horizons.*

On the whole, fault strike orientations were measured in each mapped horizon ranging from several hundreds to more than one thousand measurements.



## REGIONAL GEOLOGICAL SETTING

The tectono-stratigraphic history of the studied

Figure 3 – Uninterpreted and interpreted SW-NE orientated seismic profile (random line) extracted from the 3D seismic volume.

area has been influenced by seven episodes developed above the Paleozoic craton: 1) Early to Middle Jurassic rifting, 2) Cimmerian compressive event, 3) Early Cretaceous rifting, 4) Late Cretaceous passive margin evolution 5) Upper Cretaceous-Paleocene Laramian compressive event, 6) Early Oligocene-Miocene Gulf of Suez rifting and 7) Red Sea break-up.

The stratigraphy of the area is composed of sediments ranging from Jurassic to Tertiary age and include: 1) Lower to Middle Jurassic clastic units of Bahrein and Khatatba Fms., 2) Middle to Upper Jurassic carbonates of Masajid Fm., 3) Barremian clastic units of Alam El Bueib Fm., 4) the Aptian Alamein Dolomite Fm., 5) Albian to Cenomanian clastics of Kharita and Bahariya Fms., 6) the Upper Cenomanian to Coniacian alternation of clastic and carbonates of Abu Roash Fm., 7) the Coniacian to Danian carbonates of Khoman Fm., 8) the Paleocene to Upper Eocene carbonates of Apollonia Fm., 9) the Upper Eocene to Oligocene shales of Dabaa formation and 10) the Oligocene to Miocene sandstone of Moghra formation (fig. 3), which represents the youngest formation outcropping in the Western Desert's surface.

## CONCLUSIONS

The use of recent oil exploration data addressed to regional geology studies is a valuable tool which allows to improve previous ideas based on old exploration data.

In this sense, the quality of the 3D seismic data and the use of seismic attributes has proven to be useful to better understand the main structural

trends and development of Alamein basin and its relationship with the Neotethys and Atlantic Ocean evolution.

## ACKNOWLEDGEMENTS

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## 3D GEOMETRY OF THE SEDIMENTARY INFILL IN THE SOUTHERN SECTOR OF THE GUADIX BASIN (S SPAIN): CONSTRAIN ON THE FAULT ACTIVITY

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**KEY WORDS:** 3D modelling, Guadix basin, Betic Cordillera, 3D gravity inversion.

### INTRODUCTION

The study area comprises the southern sector of the Guadix Basin (Fig. 1), an intramontane basin located at the boundary between the Internal and External Zones of the central Betic Cordillera (S Spain). The basin is surrounded by the reliefs of Sierra Nevada towards the S-SW and Sierra de los Filabres towards the E, two large antiforms developed due to the NW-SE to N-S regional convergence between the Eurasian and African plates since the Serravallian-lower Tortonian. Since the latest Miocene, and linked to the progressive relief uplift, the basin was continentalized.

The sedimentary infill of the basin is mainly constituted, from bottom to top, by Serravallian-lower Tortonian continental to deltaic conglomerates, Tortonian marine calcarenites and marls, and latest Tortonian to Quaternary continental sandstones and conglomerates (Soria et al., 1998). Its basement is formed by metamorphic rocks (schist, quartzites and marbles, among others) belonging to the Internal Zones. The area is mainly deformed by NW-SE normal faults (Sanz de Galdeano et al., 2012).

### METHODOLOGY

A 3D geological model was built to determine the deep structure of the southern sector of the Guadix Basin (1500 km<sup>2</sup>), using 3D GeoModeller and GOCAD codes. The procedure comprises two phases: i) development of an initial model integrating all the geological and geophysical information (geological mapping, structural data, 319 lithological columns of boreholes, 348 vertical electrical soundings, 3 electric tomographies and 17 time-domain electromagnetic soundings) along with new structural data, and ii) refinement of the model based on the 3D gravimetric inversion that

provides additional information in areas lacking borehole data.

The topographic surface was extracted from the 5 m Digital Elevation Model (DEM) of the Spanish Instituto Geográfico Nacional (<http://www.ign.es/ign/layoutIn/modeloDigitalTerreno.do>). The lithological contacts and faults were set (digitized and georeferenced) from previous geological maps and locally modified after field work and photo interpretation.

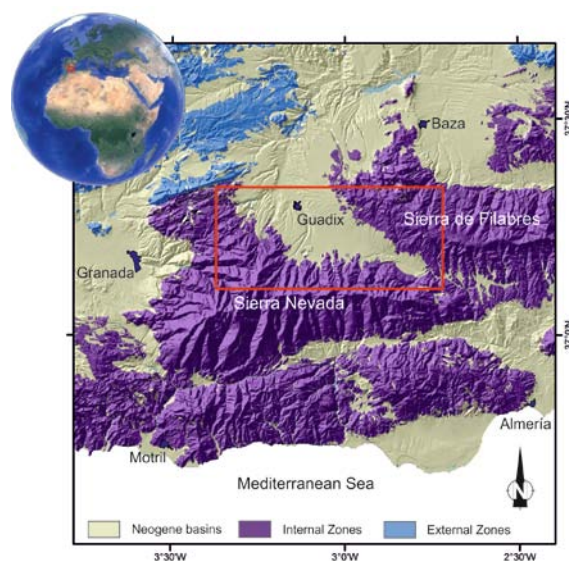


Figure 1 – Location of the study area in the geological context of the Betic Cordillera.

The 3D gravimetric inversion was accomplished using 3D Geomodeller. A total of 714 gravity stations (Sanz de Galdeano et al., 2007) were processed to calculate the Bouguer anomaly, with a reduction density of 2.67 g/cm<sup>3</sup> and using the GRS67 Geodetic Reference System. The density value assigned to the basin infill (2.30 g/cm<sup>3</sup>) was determined through a 3D gravimetric inversion of the central part of the studied area, where the model geometry was accurately established through boreholes.

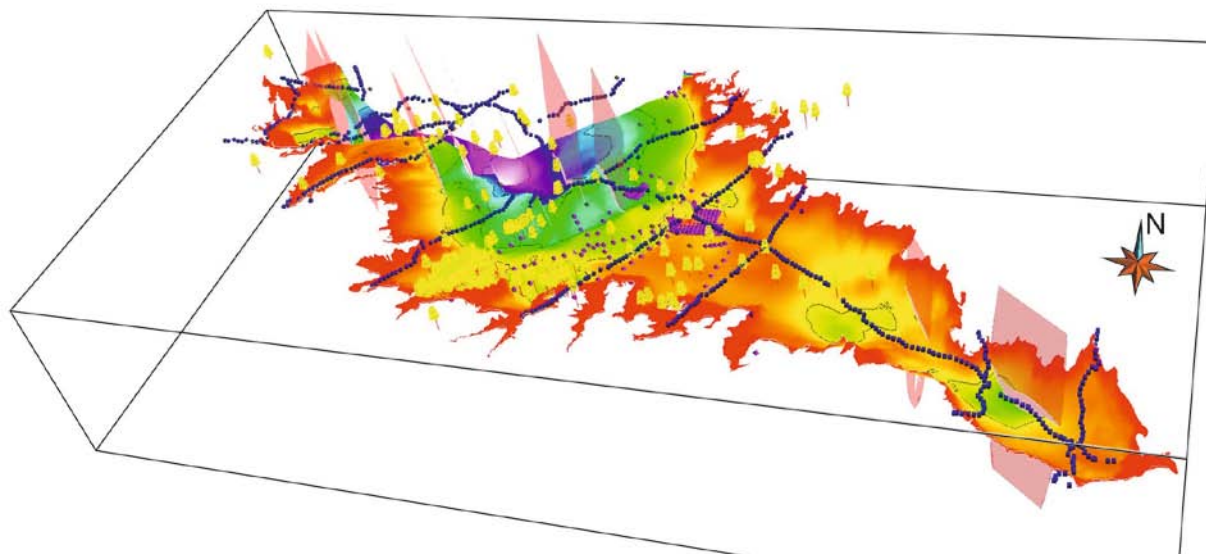


Figure 2 – 3D block diagram of the bottom surface of the Guadix Basin sedimentary infill. Red surfaces correspond to the modelled faults; Boreholes (yellow derricks), gravity stations (blue cubes), vertical electrical soundings (pink diamond) and time-domain electromagnetics (brown diamonds) are represented. The geographical location of the block diagram is indicated in Figure 1.

The residual anomaly, obtained after the removal of the regional anomaly, was modelled and allowed us to establish the thickness of the sedimentary infill, to test the initial 3D model, and to refine it in areas where the borehole and geophysical data coverage was sparse.

## CONCLUSIONS

The main basin depocentre is located at the central sector of the basin with a maximum thickness of up to 1100 meters. Its geometry is controlled by NW-SE normal faults to the north meanwhile its southern boundary is gradual. There is another depocentre less pronounced (~300 metres) at the southeastern end of the basin also related to the presence of NW-SE normal faults. Both depocentres are separated by a basement high in the central sector of the modelled area, where the basin only has around 150 meters of sedimentary infill.

The basement top is offset for hundreds of metres along the NW-SE normal faults. Faults offset is reduced to ten of meters at surface, using upper Quaternary layers as deformation marker. This fact indicates that (i) the faults were mostly developed during the sedimentation of the basin and (ii) they were active up to Quaternary times.

## ACKNOWLEDGEMENTS

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## Brandenburg 3D – GIS goes underground – a geological 3D model for the public

Maik Schilling <sup>(1)</sup>; Christoph Jahnke <sup>(1)</sup>, Andreas Simon <sup>(1)</sup> and Thomas Höding <sup>(1)</sup>

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**KEY WORDS:** geological 3D model, web, public.

### Introduction

The necessities in conversion of energy industrie, called “Energiewende” as well as the increasing scarcity of raw materials will lead to an intensified utilization of the subsurface in Germany. Within this context, 3D geological modelling is a fundamental approach for integrated decision and subsurface management processes. Initiated by the development of the European Spatial Data-Infrastructure INSPIRE, the German State Geological Offices started digitizing their predominantly analog archive inventory. Therefore the project B3D strives to develop a new 3D model as well as a subsequent infrastructure node to integrate all geological and spatial data within the Spatial Data Infrastructure Brandenburg (GDI-BB) and provide it to the public through an interactive 2D/3D web application. The project B3D is funded with resources from the European Fund for Regional Development (EFRE).

### Initial Data

To create the geological 3D model of Brandenburg, a number of analog input data was used, e.g. borehole data, seismic cross sections and seismic maps (Table 1).

borehole data	620
seismic cross sections	2520
seismic maps	236

Table 1 – Selected data for modelling.

From these data, a comprehensive geological 3D model of Brandenburg was constructed. This model encompasses the most important regional seismic horizons, along with a large-scale fault-network and a detailed Zechstein-salt surface. Also two detailed models to the east and south-east of Berlin have been constructed, which are also available through the web application. To provide an efficient workflow, the individual work packages have been executed simultaneously. The overall workflow for the digitization and the modeling part of the project is shown in Figure 1. All data has been stored, regardless of format, in a new data infrastructure including a new designed database called GeoDaB.

### Data infrastructure and web application

The new developed infrastructure follows a three-level client-server-architecture and is built with Free and Open Source Software. At the first level we integrated an export tool for the well archive and stored all new data in a PostgreSQL database that can be accessed with tools such as ArcGIS and GoCAD through customized interfaces. To store the 3D data the software GST is used.

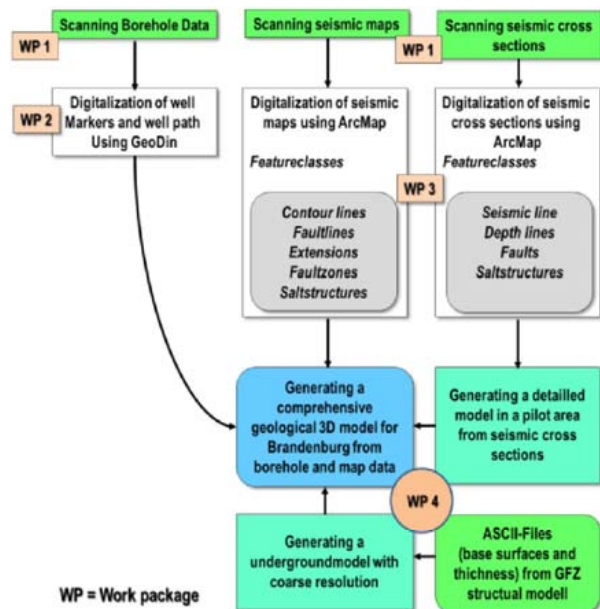


Figure 1 – Workflow for digitization and modelling.

We implemented a publishing tool that allows the publication of approved 2D and 3D data sets to a web server at the second level that in turn provides it through OGC services, hosted by Geoserver, to the web application and with this to the public. At the third level the web application is located. What we wanted to do was to develop a web application that features a classical 2D client („2D Mapviewer“) and also a 3D client („3D Earthviewer“) with components typical of a WebGIS like an overview-map and a layer-tree. On the client side, the web application leans on the JavaScript API WebGL that allows the interactive rendering of 2D and 3D graphics which does not require the use of additional plug-ins. WebGL is supported by most web browsers. For the 2D Mapviewer the JavaScript Frameworks OpenLayer, GeoExt and ExtJS were used which

provide the Graphical User Interface, dynamic map content and the display of map interface components such as a legend, a layer opacity slider, attribute display tables, and zoom functions. The 3D Earthviewer follows a similar structure as the 2D Mapviewer but is enhanced by the X3DOM library for the presentation of 3D content.

To make the results of B3D available to external users, e.g. scientists, economy and the public, the web portal "Brandenburg 3D" was developed. At its homepage there are some general information about the project, the functionalities and the involved partners. From the homepage one also gets access to the 2D- and 3D-viewer. The 2D Mapviewer has a variety of functions that are known from other regular WebGIS clients e.g. tools for navigation, loading external WMS, changing of spatial reference systems, and a styler to change the appearance of the maps.

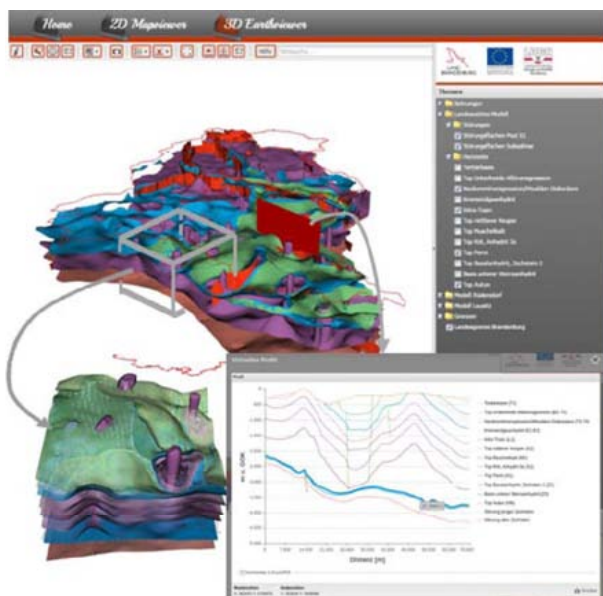


Figure 2 – 3D-Viewer within web application showing overall model, model with original resolution and virtual cross-section.

In addition we developed a number of extra tools that grant access to the third dimension of the geodata. For example we have a special filter and search functionality that returns the boreholes and seismic cross sections with defined properties e.g. length, age or stratigraphic units. One can also request detailed meta-information on individual well locations and seismic lines by clicking on them within the map. The 3D-Viewer has almost the same look and feel like the 2D-Viewer. In the 3D-Viewer it is possible to move freely within the model and to make individual layers (in)visible interactively. You also get attribute prompts through a mouse-over functionality, which works in the same way in the 2D client. A central feature is the possibility to create virtual boreholes or cross-

sections at any arbitrary position within the model and also at the map. Within the 3D-Viewer also the virtual well path or seismic cross section is visualized. The profiles that get generated through this method can be exported to a PDF. To provide a fast visualization and interaction with the 3D model, all data within the web application are generalized. One can have a look at the original data resolution within a bounding box of 10x10 km through a special functionality of the 3D-Viewer. Besides it is possible to visualize the nodes that build the surface.

Due to a legal dispute, the geological survey of Brandenburg is currently not allowed to publish any data generated within the project Brandenburg 3D.

### Next Steps

Within the project "TUNB" - *geopotentials of the deep underground in the Northeast German Basin* which started at the end of 2014, the existing 3D model shall be enhanced. Until 2020 the project aims to build a structural 3D model of the whole Northeast German Basin to evaluate potential utilization of the deep underground like geothermal energy or underground storage. Based on a harmonized lithostratigraphical classification the state geological surveys of Schleswig-Holstein, Lower Saxony, Mecklenburg-Western Pomerania and Brandenburg update their existing 3D models, create new models and bring them together to build an overall model of the Northeast German Basin. The project is funded and coordinated by the Federal Institute for Geosciences and Natural Resources. Furthermore we keep on working on the web application. In the near future the system should be extended by additional functionalities and additional data, for example it should be possible to view seismic cross sections in the 3D viewer or to integrate parametric voxel models, time series or sensor data into the web application. It is also conceivable to advance the query functions to deal with the different parameters of the 3D model to locate areas with certain temperatures, which occur for possible use as a geothermal site. Also the integration and analysis of time-varying data is possible.

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## INTERPRETATION AND VISUALIZATION OF SEISMIC AND BOREHOLE DATA FOR A 3D MODEL IN THE SOUTHERN BALTIC SEA, EAST OF RUEGEN ISLAND (GERMANY) AS PART OF THE USO PROJECT

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**KEY WORDS:** *Baltic Sea, Mecklenburg-Western Pomerania, off-shore 2D seismic, Tornquist-Teisseyre Zone, Adler-Kamien Fault System.*

### PROJECT INFORMATIONS

The University of Greifswald and the Geological Survey of Mecklenburg-Western Pomerania (LUNG M-V) started in 2012 the research project USO ("Untergrundmodell Südliche Ostsee") to develop a 3D structural model of the subsurface of the southern Baltic Sea area. The project area is subdivided into a western and an eastern part.

East of Rügen Island, numerous offshore reflection seismic profiles, measured in the 1970ies and 1980ies by the organisation "Petrobaltic" (a joined research group of the former German Democratic Republic, Poland and the Soviet Union) are the major data base to characterize the complex geological succession since the Proterozoic. These seismic profiles were partially re-processed in the 1990ies during the BGR research project SASO ("Strukturatlas südliche Ostsee"; SCHLUETER et al. 1997), and more recently, by the CEP Ltd. for oil and gas exploration. Besides, off-shore and on-shore borehole data are used for correlation and time-depth-conversion.

### GEOLOGICAL ASPECTS OF THE SOUTHERN BALTIC SEA AREA NORTH-EAST OF RUEGEN AND USEDOM ISLANDS

The working area comprises parts of the Precambrian basement, especially in the north of Rügen Island. Mesoproterozoic crystalline rocks and overlying Cambro-Silurian sediments are overthrust by folded and faulted primarily Ordovician sediments, which form an accretionary wedge (also called Rügen Caledonides; KATZUNG et al. 2001). Remnants of Devonian and Carboniferous sediments are preserved locally. A thin layer of volcanic rocks and a large pile of sediments were deposited

between Permian and Cretaceous times. This succession represents the evolution of the North German Basin (NGB), especially at its north-eastern margin. This syn-sedimentary intracontinental basin system extended from the southern Baltic Sea area in the North to the Harz Mountains in the South (KRAWCZYK et al. 1999).

The distribution of the sediments is not only controlled by the palaeogeographic situation but also by tectonic movements including halokinetic processes. Re-activation of older faults within the Tornquist fan (e.g. THYBO 2000) during Mesozoic and Cenozoic times led to the formation of complex fault systems. The most prominent tectonic structures within the working area are the western faults of the Tornquist-Teisseyre Zone, named Adler-Kamien Fault System. Other, minor faults, which often border graben structures, belong to the West Pomeranian Fault System (Vorpommern Störungssystem = VPSS; KRAUSS & MAYER 2004).

### STEPS TOWARDS THE 3D MODEL

All the available seismic and borehole data have been integrated and illustrated within an Arc GIS project.

First, analog maps of several horizons prepared during former investigations were georeferenced and digitalized.

In a second step 150 re-processed profiles with a total length of about 3120 km and four offshore wells with logs could be imported into the "SeisWare™" software package. Afterwards important marker horizons and tectonic structures like fault systems were picked along the 2D-lines with regard to the logs of the Petrobaltic off-shore wells G14, H2, H9 and K5. The gridded marker horizons as well as tectonic structures and triangulated faults crosscutting the gridded horizons could be imaged using the "SeisWare - 3D Visualizer".

In a next step the program MOVE™ (Midland Valley) is used to restore single 2D-cross-sections and continue modeling.

### ACKNOWLEDGEMENTS

We gratefully acknowledge Central European Petroleum Ltd. (CEP) for financial, technical and scientific support. For providing additional seismic lines we also thank the Federal Institute for Geosciences and Natural Resources (BGR) in Hannover.

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## DATA MODEL FOR A NEW DIGITAL QUATERNARY MAP OF SPAIN 1:1,000,000

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**KEY WORDS:** Data Model, Quaternary deposits, INSPIRE, IQUAME

### INTRODUCTION

The Geological and Mining Institute of Spain (IGME) has generated lots of cartographic information at different scales, which has been an important tool used in the design of public works, hydrogeological and raw materials survey, geological hazards, environmental assessment, etc. Due to the advances in the tools used to develop and transfer cartographic information (GIS, Web Map Servers, etc.), as well as the progress in the geological knowledge, it is necessary to update the current information regarding to geoscientific contents and technical aspects such as: formats (paper, raster or vector), data models (according to the new INSPIRE directive requirements), or geometrical and geographical accuracy.

Good examples are the geo-thematic maps published by the IGME during the last years: Quaternary Map of Spain at 1 million scale (Pérez-González et al., 1989) paper map, vectorized in 2010 without any update; Geomorphological Map at 1 million scale (2004, paper and raster format), Lithostratigraphy and Permeability Map 1:200,000 scale (2004, vector format), etc.

At an international scope, the first International Quaternary Map of Europe 1:2,500,000 scale (IQUAME 2,5M), promoted by INQUA-BGR (1967-1995), could be an example of a very similar issue. Currently, in a cooperative framework, INQUA, CGMW and BGS are coordinating a new vector and updated version of IQUAME 2.5M (Asch, 2011). The IGME will provide the cartography corresponding to the Spanish territory.

### 1:1,000,000 SCALE QUATERNARY MAP OF SPAIN. DATA MODEL

In order to achieve this goal, the IGME has designed a double-aspect objective: to update the information of the Quaternary Map of Spain at 1 million scale, developing a data model consistent with the INSPIRE directive and the technical requirements defined for the new IQUAME 2,5M (Asch et al, 2014).

The Data Model here presented shows the organization, structure and nomenclature of the cartographic information generated for the new version of the Quaternary Map of Spain (1 million scale).

**Organization:** All the information data generated in this project will be stored in hierarchic folders and sub-folders, as follows: "Quaternary\_1M\_2016" folder, named according to the project name and the expected end year. Three sub-folders which will store: cartographic information (ProjectData), metadata as independent files (Metadata), information related to the project structure and organization (Contents). ProjectData sub-folder is again subdivided into four sub-folders: AuxiliaryInfo, SpatialData, Documents, Maps, ProvisionalInfo.

**Technical specifications:** it has been defined ETRS89 UTM-H30 as the projection and coordinate system for the Peninsula - Balearic Islands context, and REGCAN95 UTM-H28 for the Canary Islands. Legends, auxiliary diagrams and credits will have no projection system assigned and they will be digitized at a 1:1 scale. The Topographic and planimetric base used here will be a simplified version of the IGN map at 1:1,250,000 scale.

#### Structure and nomenclature (coding):

Main constituent elements in the Quaternary Map of Spain are grouped into several thematic classes: Quaternary deposits, Quaternary landforms (geomorphological info), Annotations - other texts - auxiliary drawing features (geographical context diagrams, etc.), and Credits and auxiliary diagrams (projection system data, symbology, map date, official logotypes, etc.).

Graphical data corresponding to the different thematic classes will be stored in an ArcGis- file Geodatabase named Cuaternario\_1M\_2016.mdb. Inside this geodatabase we will find different FeatureClass files (polygon, line, point, text and alphanumeric table).

The Quaternary Map consists of three main groups of information: main map (1), other elements related to the main map (2), auxiliary diagrams and map credits (3). Each one of these

groups corresponds to a different FeatureDataSet: QuaternaryPB\_1M, QuaternaryIC\_1M, LegendQ\_1M, PerimeterQ\_1M.

**1. The Main Map** includes graphic elements related to Quaternary deposits, which are stored in two FeatureDataSets: QuaternaryPB\_1M (peninsula and Balearic Islands) and QuaternaryIC\_1M (Canary Islands). This duplicity is due to the different system projections, necessary in two different geographical contexts.

The aforementioned FeatureDataSets contain the following FeatureClasses: Quaternary deposits (polygon), limits of Quaternary deposits (line), Quaternary landforms (polygon), active faults (line), linear features -no geological contacts or faults- (line), Quaternary features of punctual representation (point), other features and symbols associated to the deposits and landforms (line), annotations and other texts (text).

**2. Other elements related to the main map (legends and tables)** are included into the LeyendaQ\_1M FeatureDataSet, which contains the following FeatureClasses: polygons of the Quaternary map legend, auxiliary feature lines of the Quaternary map legend, feature points of the Quaternary map, and texts for the description of the Quaternary deposits. The same structure will be applied to the landforms legend.

**3. Auxiliary diagrams and credits** of the map contain polygons, lines, points, annotations and auxiliary drawing elements, all of them included in the PerimetroQ\_1M FeatureDatSet.

All FeatureClass are defined by the following fields: Field (Name), Type and Description.

Finally, coding tables for lithology, stratigraphy-age and genesis (environment and process in INSPIRE) have been defined. All these codes are consistent with the specifications and vocabularies of the INSPIRE directive requirements. Coding tables for geological contacts and fault types and auxiliary drawing lines, are also included in this data model.

## CONCLUSIONS

The cartographic contents and the data model for the Quaternary Map of Spain at 1M scale have been designed considering technical and geological required for the new digital IQUAME 2.5M and also the INSPIRE directive requirements.

Quaternary geological information of the Spanish territory will be conveniently generalized to supply the required cartography information

layers for the IQUAME 2.5M (Stratigraphy-Age, Lithology, Genesis: Event Environment – Event Process, Geomorphology, Glacial Maximum limits, Active faults, Quaternary important sites, etc.).

## ACKNOWLEDGEMENTS

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## THE ROLE OF 3D MODELLING IN THE URBAN GEOLOGICAL MAP OF CATALONIA

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**KEY WORDS:** *urban geology, 3D geological modelling, near-surface, structural analysis.*

### THE PROJECT

Since 2007, the Institut Cartogràfic i Geològic de Catalunya develops an urban geological project with the objective to provide both accurate and relevant geological information of areas with major anthropogenic activity of Catalonia (Pi & Vilà, 2013). In short term, the project will be focused on the geologic characterization of county capitals and towns with a population larger than 10.000. This represents 131 municipalities hosting ~6.2 million inhabitants and a study area of 2.200 km<sup>2</sup>. It is worth to mention for its magnitude the Barcelona Metropolitan Area which includes Barcelona city and 35 neighboring municipalities, with ~3.2 million citizens in an area of 636 km<sup>2</sup>.

The project integrates in a GIS environment pre-existing cartographic documentation, core data from compiled boreholes, descriptions of geological outcrops within the urban network and neighboring areas, petrological/physical/chemical characterization of representative samples and detailed geological mapping of Quaternary, pre-Quaternary and artificial materials.

The analysis and synthesis of the resultant urban geological information system allows the edition of the 1:5.000 scale Urban Geological Map that has been sectorized into 260 map sheets of 8 km<sup>2</sup>. Each map sheet is self-consistent, but is conceived as a part of a whole of the urban geological project. Geology of the different areas is characterized using similar criteria and continuity between surrounding areas is granted.

The integration of geological and anthropogenic deposits models is essential to characterise the full range of subsurface conditions in urban environments (Culshaw & Price, 2011). This is one of the main premises of the Catalan geological urban mapping project.

### GEOLOGICAL UNITS OF THE URBAN AREAS

The geological framework where the different urban areas of interest are located suggests the

necessity to reveal the underground structure of the following main lithostratigraphic units:

- Anthropogenic deposits such as road embankments, infilled river beds, coastal settlements, materials filling quarries and other relevant artificial deposits.
- Holocene fluvial and coastal deposits associated with the global deceleration of sea-level rise that occurred since ~8500 BP.
- Pleistocene alluvial and colluvial deposits that cover heterogeneously the plains and the footslopes.
- Neogene sediments related to the system of extensive basins that compartmentalize the Mediterranean margin.
- Paleogene sedimentary sequences of the Ebro Basin related to the Alpine orogenesis and the uplift of the Pyrenees and the Catalan Coastal Ranges.
- Mesozoic sedimentary sequences related to the evolution of the Iberian Plate during the opening of the Tethys and Atlantic oceans.
- Magmatic and metamorphic rocks related to the late-Hercynian tectonothermal events.
- Paleozoic sequences of the northern Gondwana margin affected by Hercynian folding phases.

### 3D MODELLING METHODS

To address the underground geological structure and properties of the geological units we have established a set of 3D modelling methodologies. These methodologies pay special attention to the structure of the near surface, the part of the underground which most directly influence the urban environment. The 3D reconstructions that are carried out for each map sheet depend on the information available and the geological features of each study area. In synthesis the main 3D modelling methods implemented are:

- Determination of elevation changes, including infilled and excavated areas basically related to human activity derived by comparing the digital terrain models of two different times, one from the present and the other from the 1960's.
- Determination of the base of the Quaternary (Holocene and Pleistocene) and Neogene deposits obtained from the delineation of contour lines at 5 meter intervals and seriated cross sections taking into account borehole data, geomorphological features, detailed geological mapping and H/V measures.

- Determination of the structure of multilayer sequences (basically Mesozoic, Paleogene and in some cases Neogene) applying the dip-domain method, that consists in the compartmentalization of geological horizons in sectors where bedding orientation is approximately constant separated by lines of locally sharp curvature (Groshong, 1999).
- Determination of regular grids of regional planar geological structures (e.g main foliation of the Cambro-Ordovician terrains) derived from the interpolation of field measurements of the dip direction and the dip (Gunther, 2003).
- Determination of complex basement structures from interpolation of data derived from multiple cross sections and contour lines after a detailed structural analysis of the data.

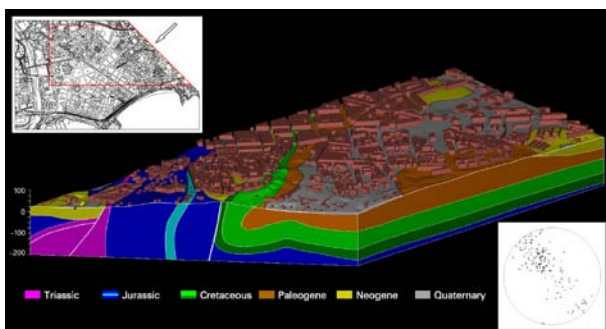


Figure 1 – 3D view of the geological structure of a sector of Tarragona's city center.

## INFORMATION MODELLING ENVIRONMENT

3d geological models are basically built using the MicroStation CAD software, a leading information modelling environment for urban planning and management of many urban infrastructure types. MicroStation provides extensive format interoperability (dgn/dwg/dxf, 50+ image formats, shp, universal 3D, etc.), a complete system of geometric and data management applications, flexible file georeferencing, powerful visualization tools and easy programmatic extensibility. We use TerraModeler, a terrain modelling application built on top of MicroStation, that enables the creation and analysis of underground geological surfaces and that is very useful to project 3D elements into a profile and vice-versa. Moreover, we have implemented a set of MicroStation Basic macros assisting to the 3D analysis and reconstruction of geological surfaces. Besides MicroStation and their associated tools, we also use other applications such as Saga, Surfer or GeOrient to solve specific tasks of the 3D modelling workflow.

## DISCUSSION

Presently, the role of 3D modelling in the Catalan urban geological project is oriented to

build different components of the geological map sheets such as the pre-Quaternary basement map, the cross sections, and the isopach map of the Quaternary and Anthropocene deposits. The different types of 3D reconstructions are built following a workflow based on an exhaustive structural analysis. In synthesis, each map sheet can be envisaged as a product derived from a geological model, with the aim to facilitate the identification, characterization and correlation of the geological materials and structures that define the soil and subsoil.

The resulting 3D surfaces can be distributed by means of meshes, contour maps or 3D visualization files. This requires an additional effort that with few resources can be achieved.

Currently, many urban communities are immersed in the Smart City fever. Urban geology can be considered as a basic layer of this trending topic, for example to assess the vulnerability and resilience of the urban subsurface to future environmental change. In this context, it is feasible that in the near future 3D geological models will be integrated in the virtual 3D city models, following for example the CityGML application schema. This is possible and represents an opportunity for the geoscientific community.

Despite these advances, it must be taken into account that the value of urban geology is not fully recognized by the wide range of potential users. Most Catalan city authorities do not have the resources or the enthusiasm to integrate basic urban geology in their environmental information systems for planning. Culshaw & Price (2011), after a global revision of the state of the art of urban geology have announced this situation and in general encourage all geologists working in the urban areas to demonstrate the benefits of urban geology in terms of cost and environmental improvement. Perhaps 3D geological modelling could be a window to communicate better these benefits.

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## 3D SEISMIC DATA IN HYDROCARBON EXPLORATION: EXAMPLE FROM THE WESTERN DESERT (EGYPT)

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**KEY WORDS:** 3D seismic volume, hydrocarbon, faulting, Egypt.

### INTRODUCTION

The seismic reflection methods applied to hydrocarbon exploration are constantly in development. This method consists in the record of an artificially produced wave that propagates and rebounds until reaching surface receivers. The time evolution of this record provides a graph that can be interpreted in terms of stratigraphy and tectonics.

Classically, the seismic reflection method was an array of receivers in a line which providing a

vertical 2D section, known as seismic profile. If at the same time are acquired multiple parallel close seismic profiles, the resulting data will be dense enough to become a 3D seismic volume.

The main advantage of using seismic volumes instead of using the 2D seismic profiles is that the subsurface geometry of the geological bodies and fault framework could be interpreted in the three dimensions, reducing exploration uncertainties.

### METHODS

The interpretation and modeling of a seismic volume requires a sophisticated software that can process a big amount of data. In this work we used the Petrel 2013.6 platform (Schlumberger).

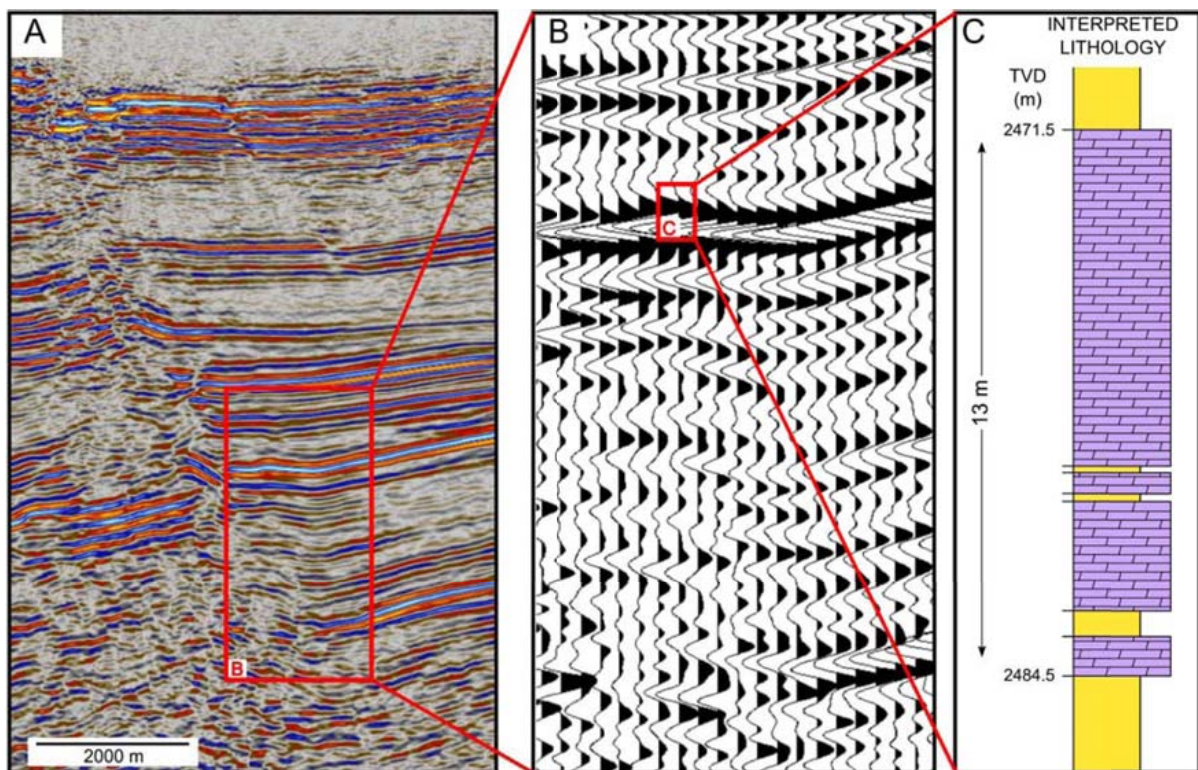


Figure 1 – A: Cross section of a 3D seismic profile. B: Detail of the previous cross section, with a wiggle display showing the resolution of acquisition. C: Interpreted lithology from a well log in the area: Purple = Dolomite and Yellow = Sandstone. Notice that in 2500 m depth the vertical resolution of the seismic data is about 15 m.

This software has been used to load a digital seismic volume of the South Alamein concession (onshore Western Desert of Egypt), well data and surface information such as digital elevation models.

## EXAMPLES

The resolution of the seismic volume permits to characterize geological bodies with a vertical resolution of 15 m at depths of thousands of meters (fig. 1). This resolution largely enhances the prospection and evaluation of hydrocarbon traps. In this case 3D, the volume of hydrocarbon contained in reservoirs can be easily estimated (Moretti *et al.*, 2010).

Resolution is also enhanced in terms of fault network understanding. Unprecedented estimations of tectosedimentary evolution are achieved. The 3D model of the fault network in Alamein Basin permits to define the structural style of the basin in detail. We can establish the relationship between major faults and minor ones in a rifting setting with a transtension component (Rodríguez-Salgado *et al.*, 2015).

Moreover, the outcropping faults only represent a small part of the real fault network, which downwards increases its complexity (fig. 2). The study of the subsurface faulting adds important structural and regional information to the model. This information can be crucial to outcome the regional structural style of the basin.

The detailed 3D mapping of surfaces (fractures, stratification surfaces, unconformities...) provide accurate geometry characterization with lower uncertainty and with

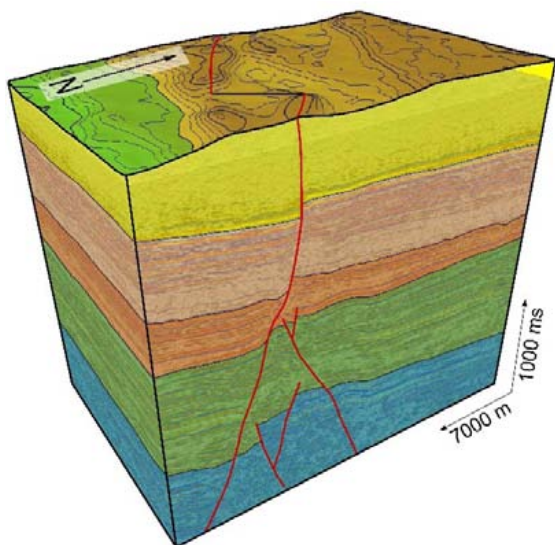


Figure 2 – Surface and subsurface expression of faulting. Blue = Jurassic, Green = Cretaceous, Orange = Eocene, Light orange = Oligocene and Yellow = Miocene.

higher resolution that will provide an enhanced estimation of the hydrocarbon volume contained in the reservoir (fig. 3). This higher resolution becomes more important in complex tectonic settings, such as inverted basins or foreland basins.

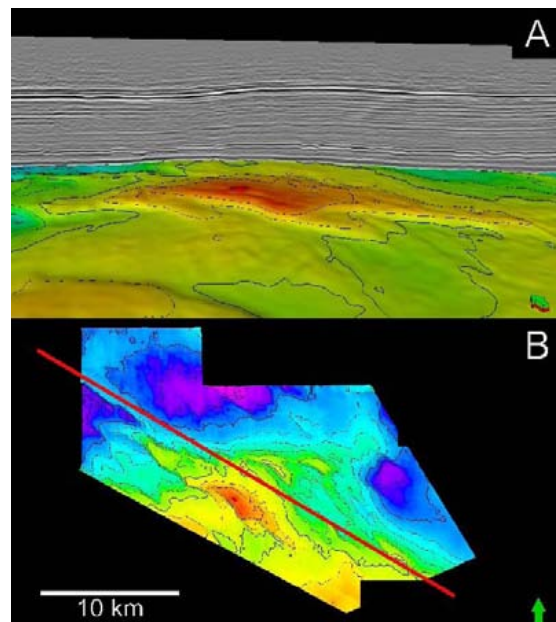


Figure 3 – 2D seismic profile (grey colors in A and red line in B) extracted from 3D seismic data. The 2D structural information could roughly predict reservoir location in top of a gentle anticline. 3D data (colored horizon in A and B) shows how best reservoir target is located slightly southwards of the red line (simulated 2D data).

## CONCLUSIONS

An example of 3D seismic surveys is used to illustrate its resolution in the case of the Alamein Basin. The understanding of subsurface geology is largely enhanced, reducing the uncertainty in hydrocarbon exploration. Regional geology can largely benefit from this kind of information.

## ACKNOWLEDGEMENTS

Schlumberger kindly provided the Petrel platform for this study.

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## FROM DIGITAL TERRAIN MODEL TO SHADED RELIEF – PRACTICAL EXAMPLES FROM THE BAVARIAN ENVIRONMENT AGENCY

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**KEY WORDS:** cartography, relief, digital terrain model (DTM), shaded relief, 3D visualization, ESRI ArcGIS, Adobe Photoshop, Blender

### INTRODUCTION

The Bavarian Environment Agency produces a wide range of publications and maps covering manifold environmental topics. A recurrent requirement for maps is the representation of terrain as shaded relief to give an impression of the terrain, to make illustrations more descriptive or to incorporate additional data such as geological or hydrological information or functional data i.e. for emergency management, avalanche warning services, landscape architecture, etc.

This results in the need to develop methods for creating a digitally shaded relief comparable with the quality of a hand-drawn shading.

The requirements are:

- Usability in a wide scale range for overview and detailed maps, prerequisite for this is a sufficiently high resolution
- Large landforms should be highlighted
- Possibility to adapt the contrast individually to the landscape, exaggerate the plains, reduce mountainous areas
- The application of colour must be so subtle that other map elements remain readable
- Relatively rapid creation of shaded relief

### INITIAL SITUATION

Existing terrain models range from free available Gtopo30 and SRTM data to laser scan data with 5m resolution for Bavaria.

DTM	resolution	coverage	source
Gtopo30	Ca. 1km	worldwide	USGS
SRTM	Ca. 90m	Europe	USGS
DTM25	25m	Bavaria	LDBV
DTM5	5m	Bavaria	LDBV

Fig. 1 – Overview of existing digital terrain models

### SHADED RELIEF FROM ESRI ARCGIS

From a surface raster (DTM) ArcGIS creates a hillshade with adjustable azimuth and elevation angle. Further manual intervention options are not available. Fig. 2 shows shaded reliefs generated with ArcGIS which do not fulfil the listed requirements when used individually.

Reasons are, for example, data gaps (A) or insufficient resolutions of the underlying DTM.

Thus, the shading either is pixelated and too little detailed (B) or delicate and bumpy characterized (C). A regional "Bavarian problem" are extreme relief differences between lowland (Molasse) and high mountains (Alps). This results in contrast differences in the shaded relief for which an optical compensation is necessary which is not possible with ArcGIS.

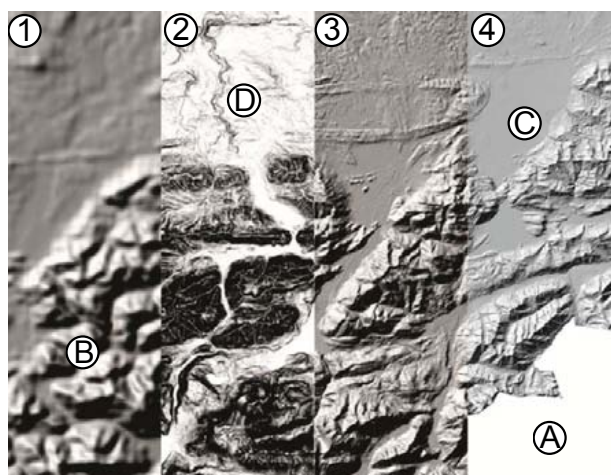


Fig. 2 – shaded relief from ArcGIS: ① Gtopo30 oblique light ② SRTM slope ③ SRTM oblique light ④ DGM5 oblique light

### COMBINATION AND REFINEMENT OF SHADED RELIEF IN ADOBE PHOTOSHOP

Fig.3 shows a two-step workflow with a combination of several shaded reliefs and their further processing in the photo-editing software Photoshop. The combination of several shaded reliefs with different levels of detail achieved a generalization effect similar to "resolution bumping" (PATTERSON). Because the shaded relief with the lowest resolution (Gtopo30) is used as a base, large landforms are recognizable. In order to improve the level of detail for large scale representations, a shaded relief with higher resolution (SRTM or DGM5) is blended with the base.

The emphasis on illuminated slopes is achieved by selecting the lights and storing them in a separate layer located above the hypsometric layer. The intensity of illumination can be varied manually in Photoshop using adjustment layers which are combined with masks for different regions. With this procedure, the dark shadows in the Alps are lightened in order to obtain a homogeneous image for entire Bavaria.

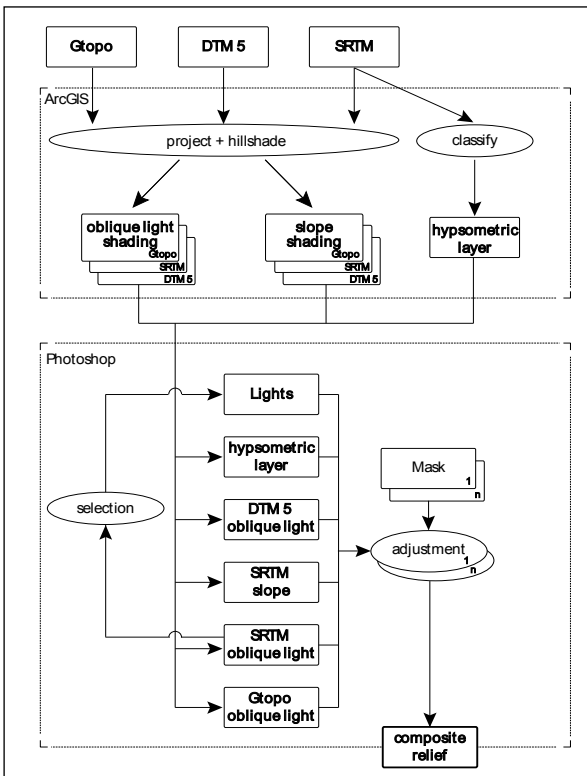


Fig. 3 – Workflow for creating and editing a composite shaded relief

To ensure that structures in the lowlands remain visible, the existing oblique light shading is combined with a slope shading (Fig. 2 and 4; D).

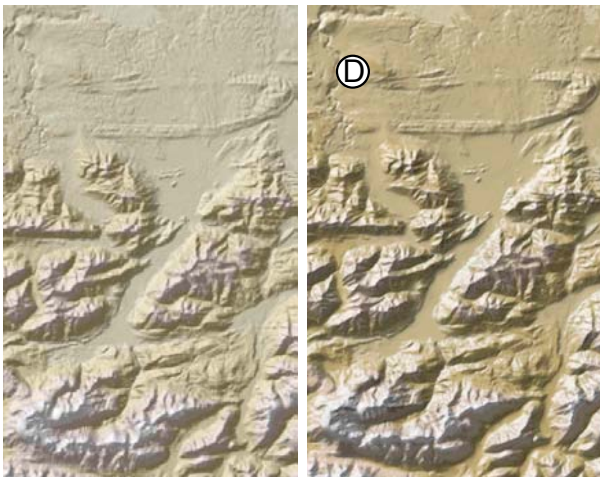


Fig. 4 – shaded relief with hypsometric layer, left: based on SRTM from ArcGIS, right: from Photoshop

Compared with the low-contrast ArcGIS shaded relief the Photoshop shaded relief represents a significant increase in quality (Fig. 4).

**SHADED RELIEF BY PHOTOGRAPHY OF A 3D MODEL IN BLENDER**

Imhoff (1965) describes the principle of photo-mechanical hillshading for which a 3D model was generated. It was usually modelled in plaster, photographed and the image then used as shaded

relief. However, this method was extremely labor-intensive and time-consuming and suffered from the limitations of coarse mechanical modelling.

The use of modern 3D computer graphics software follows the same principle. With the free and open source software Blender a shaded relief is created by modelling, illuminating and photographing a digital 3D terrain (HUFFMAN 2014). Illuminating the entire model instead of calculating individual pixels as in ArcGIS, creates a more realistic terrain impression. Large landforms are just as visible as terrain details. The contrast differences between plains and mountains can be compensated by manipulation of the terrain model.

The texture and lighting parameters are highly configurable and provide a visually appealing shaded relief (Fig. 5).

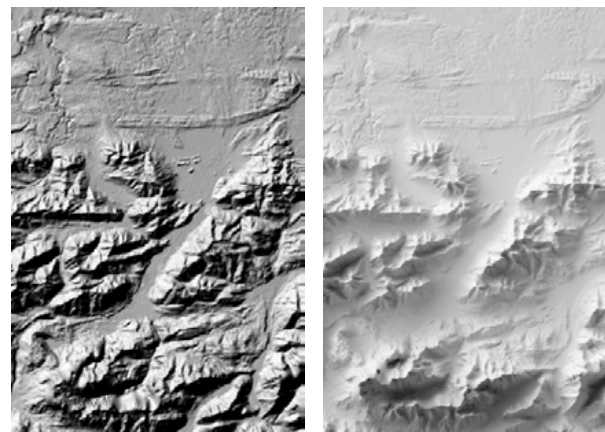


Fig. 5 – left: shaded relief based on SRTM from ArcGIS, right: shaded relief from Blender

**CONCLUSION AND PROSPECT**

Through the use and combination of GIS and graphic software the LfU is able to produce illustrative shaded reliefs for print products. A promising new method is the use of the 3D graphics software Blender to create shaded reliefs. This can complement the photoshop workflow. Blender also opens up new possibilities for another topic, which is 3D visualization. It could replace the previously used software ArcScene for generating perspective views of terrain models in combination with environmental themes.

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## On Building Large-Scale 3D Geological Models without Using Map Projections

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**KEY WORDS:** 3D Modelling, Coordinate System, Ellipsoid, Geoid.

### INTRODUCTION

3D modelling is applied with increasing frequency to large-scale regional models, sometimes spanning whole countries, but most of them are constructed on the basis of coordinate systems and/or map projections that are specific to a certain region with a limited spatial range. Among the Geological Surveys of the German Federal States, for example, the UTM (Universal Transverse Mercator) Projection is often used for managing spatial data and for turning spatial data into the Cartesian coordinate system that is needed by the standard 3D modelling systems, such as Gocad or Petrel.

When several 3D models are to be merged to generate one large 3D model or when the data from different regions, and for this reason different projections, are to be used jointly, this approach can lead to problems and become laborious as it requires the re-projection and conversion of the data back and forth. As more and more national and international projects emerge that involve large regions and several Geological Surveys, such as TUNB (Zehner et. al, 2014) or GeoMol (GeoMol 2014), these problems are becoming more and more important.

However, the approach based on using map projections for converting spatial data into Cartesian data is questionable. Why do we apply map projections at all, when constructing 3D models? Theoretically we could construct the models on the surface of a sphere (or, to be more precise, an ellipsoid or even better a geoid) using geographical coordinates (latitude, longitude and height from the curved surface). Figure 1 shows how this could look. The contours of the top Lower Buntsandstein from the GTA (Baldschuhn et. al, 2001) are shown in 3D, using the software ArcGlobe.

Theoretically it would now be possible to construct a 3D geological model on this kind of 3D data representation and this geological model could span the globe without generating any problems. Further the corresponding data could be managed in geographical coordinates which span the whole world. Unfortunately ArcGlobe does not support geological modelling algorithms, such as DSI (e.g. Mallet 2002).

The rest of this contribution will sketch out how we could arrive at the construction of a 3D model

on the virtual earth's surface, using a standard software package for geo-modelling, and what extensions are needed for this to be implemented.

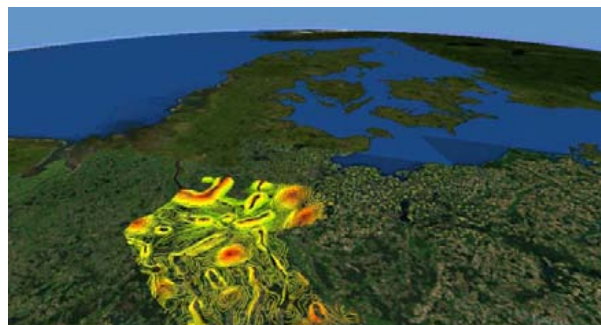


Figure 1 – 3D contours describing a geological horizon mapped on a sphere using ArcGlobe.

### COULD WE DO THIS USING GOCAD?

Gocad is not naturally intended to be used for loading data in geographical coordinates, representing them along a geoid's surface and subsequently constructing the model along such a data representation. However, Gocad's modelling algorithms are independent of the position and tilt of a surface and Gocad does not require objects to be uniquely projected along some direction, and so, for example, can have only one z-coordinate for each x-y position. Thus, if we dismiss the assumption (and often the modeller's intuitive expectation) that the sea-level in Gocad is represented by a horizontal surface, we could achieve "modelling on a geoid" by following these steps:

1. Preparing all the data, such as borehole locations and well markers, using geographical coordinates.
2. Loading the data, such as the contours above, using geographical coordinates.
3. Transforming the data onto a sphere or geoid in a Cartesian world coordinate system, e.g. with its origin at the earth's center of gravity, one unity vector pointing along the earth's axis and the other two unity vectors describing the equatorial plane, one of them pointing through the 0° Meridian (see Figure 2). The data would then spread along the geoid's surface.
4. Constructing the geological model as usual, using the standard Gocad functionality.

In order to present the idea conceptually we have loaded some data into Gocad with x- and y-coordinates denoting latitude and longitude respectively. To test the concept and for demonstration purposes we use spherical coordinates. It is clear that this will also work with ellipsoid coordinates and subsequent geoid correction. On

a sphere the transformation into Cartesian coordinates can be done using:

$$x = (r + h) * \sin \theta * \sin \varphi$$

$$y = -(r + h) * \sin \theta * \cos \varphi$$

$$z = (r + h) * \cos \theta$$

with  $r = 6,371,000.785\text{m}$  (average radius of the GRS 80 Ellipsoid),  $h$  being the height above sea-level,  $\theta$  being  $90^\circ$  minus latitude and  $\varphi$  being longitude.

Using this approach, we have loaded and transformed data from the GTA (Baldschuhn et al., 2001), namely contour lines for the Lower Buntsandstein, and for the orientation OpenStreetMap based land polygons that can be downloaded from the internet (Topf, 2015).

Based on the contour data from the Lower Buntsandstein we have constructed a triangulated surface, using Gocad's standard functionality. A screenshot of this work is shown in Figure 3.

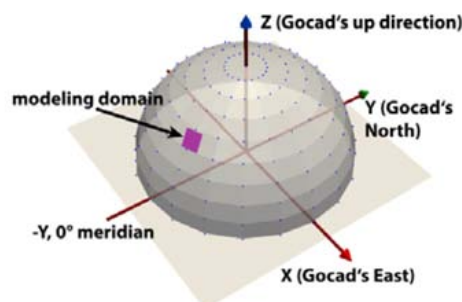


Figure 2 – Cartesian coordinate system with the origin at the earth's centre of weight, adapted to Gocad's system.

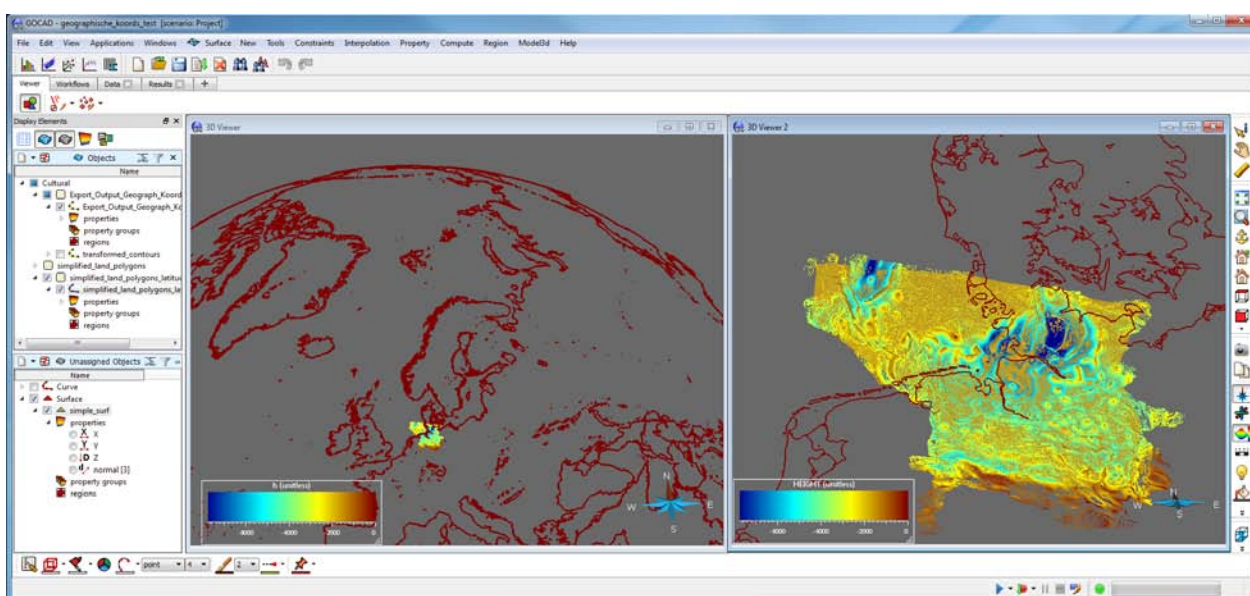


Figure 3 – 3D views in Gocad. On the left an overview, on the right a more detailed view, showing contours and a generated surface for the Lower Buntsandstein stratigraphic surface.

## CONCLUSION

Using the simplified approach presented in this article, it was possible to use Gocad nearly *ad hoc*. So, what would need to be implemented is a proper ellipsoid transformation and, if deemed necessary, a geoid correction. Both codes are more complicated but are possibly already available in the public domain. Furthermore some of Gocad's convenience functions would need to be re-implemented – for example Gocad's "view from top" command should be changed into a "view towards the earth's centre" command. Another option would be to rotate the complete modelling domain around an axis tangential to one of its central latitude circles during the modelling process, so that it is lying flat. This linear transformation can subsequently be easily inverted. However, the modeller should be aware

that the z-coordinates that Gocad shows are not completely correct as the model is slightly curved.

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## **SOILS: FUNCTIONS AND THREATS - ORALS**

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## ASSESSING SOIL BIODIVERSITY AND SOIL BIOLOGICAL ACTIVITY IN EUROPE

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**KEY WORDS:** *soil biodiversity; soil biological activity, Europe scale.*

### ABSTRACT

Soil is important as a critical component for the functioning of terrestrial ecosystems and specifically relevant for food production. This importance led to the development of a number of indicators and classifications trying to identify key parameters that would facilitate a quick assessment of the quality/productivity of a particular site. The evolution towards more integrated views of the ecosystems, and in particular the development of the concept of ecosystem services fuelled the development of similar approaches, specifically for soils. However, the complexity of soil and the difficulty to characterize this complexity has been a barrier to develop a consistent framework for the pedosphere (Palm, 2007).

The comparison of the potential of individual soil functions across the EU allows to highlight the complexity of decision making dilemmas for resources utilization but also underlines the possibilities for resource use optimization and sustainable management (Toth et al., 2013).

The approach adopted in this study follows the soil biodiversity soil function identified in the Thematic Strategy for Soil Protection (COM (2006) 231).

The largest part of the biodiversity of terrestrial ecosystems relies directly or indirectly, on soil. The most evident component of terrestrial biodiversity is represented by vegetation; the relationships between soil characteristics and vegetation assemblage have been widely and historically investigated. The most important reservoir of biodiversity however, directly related to soil, is found belowground and it is represented by the complex of organisms, ranging in size from microns to several centimetres, known as soil biodiversity. The latter is defined as the variety of all living organisms found within the soil system.

It is difficult to identify clear and unambiguous relationships between soil parameters and the overall soil biodiversity. However, as general rule of thumb, it can be considered that the higher the variety of micro-environment in the soil, the higher will be the biodiversity.

In this study, soil biodiversity and soil biological activity throughout Europe has been assessed and mapped by using critical thresholds of several indicators (pH, soil texture, organic matter, potential evapotranspiration, average temperature, soil biomass productivity, land use) which affect the conditions of soils in terms of biodiversity and biological activity. Certain scores were given to the thresholds which might regulate the soil biodiversity levels. After the score calculation, the general situation of the soil biodiversity and soil biological activity were assessed and mapped on a European scale.

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## SOIL ANALYSIS FOR SOIL MAPPING

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**KEY WORDS:** soil, soil analysis, soil mapping.

### INTRODUCTION

Soil analysis is a branch of soil science which has the objective of producing soil analytical data for furnishing soil information needs. Soil data for agricultural demands and soil data for agro environmental uses are the most common needs. Furthermore, soil mapping and research data requirements constitute important groups of analytical data demands.

Soil data needs are related to fertilizer advice, fruit tree orchard planning, soils recognition, plant nutrition, soil water and irrigation management and soil amendments, among others. Agro environmental soil data concern with the supply of organic residues (slurries, sludge, compost...), heavy metal measurements, nitrate content, soil degradation, soil erosion control, etc. All these practices rely heavily in soil monitoring procedures which always include some kind of analytical soil control. There is not a clear divide between agricultural and agroenvironmental uses, although frequently administrative entities apply different frameworks in these categories.

Soil mapping is a relevant soil science branch which has the aim of explaining and drawing the distribution and properties of soils in the landscape. Soil survey and soil mapping are important consumers of analytical data. In the process of soil survey, mapping units are defined according to its shape, extension and soil properties. Soil mapping provides relevant information concerning soil properties and its distribution in the landscape. It provides a tangible view of soils and its spatial distribution.

The characterization of soil properties during the mapping unit definition and shaping is based upon the laws and principles that explain the logic and the distribution of soil types in the landscape. Soil type is obtained throughout field work by means of external recognition, soil pit descriptions and soil augering. In this field phase soil samples are collected and submitted to specialized soil laboratories for analysis. The ultimate soil map is a combination of fieldwork, spatial analytical studies and laboratory data. The integration of a large

quantity of data is a key part in the process of soil mapping production.

Soil mapping units may be either homogeneous or heterogeneous. They are composed by soil series which integrate soils with similar soil profiles characteristics. Soil series are taxonomically related to soil classifications. Properties for assigning soil classification rely in direct observation and soil analysis (Figure 1), as well. The classification of pit profiles in the field is an essential step for assignment of soil to predefined or expectant soil series. For these classifications two data become essentials: direct observation and soil data generated in soil analysis.



Figure 1. - Data produced in soil laboratories are an essential part of soil survey and soil mapping activities.

Soil analysis comprises a number of analytical tasks applied in soil samples with the aim of obtaining precise data concerning specific soil properties. Those data are used in several points of interest. Laboratory analysis is a crucial support for soil survey. The impact of data obtained in the laboratory is essential for a proper soil definition, soil characterization and soil mapping construction (Figure 2).

### SOIL ANALYTICAL REQUERIMENTS SOIL MAPPING

An extensive set of analytical requirements are normally requested for soil classification and soil mapping. A basic list of soil data requirements includes: pH, electrical conductivity, organic

matter, soil granulometry, calcium carbonate content, salinity related analysis, cation exchange capacity, saturation ratio, gypsum contents, texture, bulk density, soil phosphorus content, etc. Specific properties are investigated in certain soils for objective classification purposes. Data are supplied on horizon basis, based upon soil pit description. In the case of augerings a fixed soil depth is established, or alternatively, soil data collection is performed by horizons with a well-known horizon arrangement.

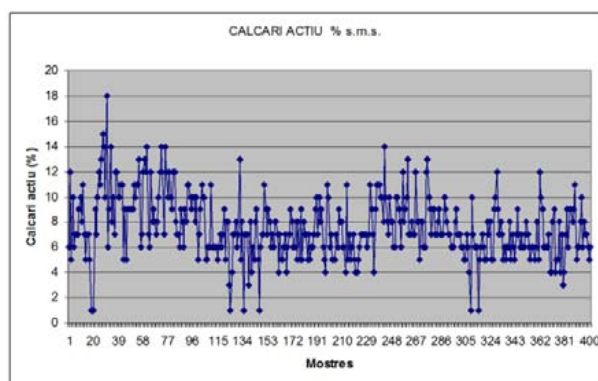


Figure 2. - Soil data vary strongly between mapping units (ex. active calcium carbonate). Data are relevant for soil mapping.

Quality control in laboratories includes an extensive number of tasks that contribute to the generation of trust and security concerning soil data. Laboratory efforts for supplying data of relevant quality include internal and external control measures. A non-exhaustive list of these procedures includes: soil inter-comparison studies, soil internal control, proper methods for the analytical objectives, laboratory accreditation (eg EN 17025), etc. An intensive work has been developed in quality control procedures although a crucial step remains critical: soil sampling. The quality of soil sampling remains, most frequently, a delicate step in the validation and the links of analytical laboratory data and field soil data.

Concerning soil methodologies a new set of analytical procedures are being introduced to accelerate the analytical work. Inter-comparison studies are necessary for a proper development and adjustment. Those methodologies relate with extractant techniques, near infrared measurements, laboratory organization, etc. New analytical equipment will supply the option of improving the scope of analytical data, due to new technologies. Turnaround times related to analytical speed within the laboratories are being reduced significantly.

Both soil description in the field and soil analysis in the laboratory are consolidated and essential steps in soil mapping production. New

developments in soil mapping production rely heavily in the reliable data generated in soil laboratory entities.

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## THE SOIL MAP OF THE INSTITUT CARTOGRÀFIC I GEOLÒGIC DE CATALUNYA

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**KEY WORDS:** soil, soil mapping, soil mapping programme, soil information, geoworks of Catalonia, geomaps of Catalonia.

### INTRODUCTION

The “Institut Cartogràfic i Geològic de Catalunya” (ICGC) was created on January 2014. Their duties are related to the competences of geodesy and cartography and about the spatial data infrastructure of Catalonia, and also to the competences of promoting and carrying out the actions related to the awareness, survey and information about the soil and subsoil.

In order to perform this task, the ICGC has to execute, in collaboration with other organizations and/or private companies when needed, different works related to soil mapping, land evaluation and land protection.

It is in this context that the ICGC has decided to continue the soil mapping programme, established on June 2009 by the former Geological Institute of Catalonia (IGC), as the best strategy to generate, store, process and spread the soils information of Catalonia.

One of the main aims of this project is the publication of the soil map (1:25.000) of Catalonia.

### CHARACTERISTICS OF THE SOIL MAP

The soil map of the ICGC is going to be distributed according to the 304 sheets of the topographical map of Catalonia (Figure 1).

The map is basically intended for technicians with some experience in the handling and reading of soil maps and, with certain limitations, to other unskilled users.

Information is structured around the map to allow different reading levels, from the most basic, in which the user identifies the type of soil at a specific spot in the area (two dimensions), the deduction of what may appear at a particular point through the sequence of horizons (three dimensions) to the interpretation of the suitability

of soils for different scenarios that may arise (soil evaluation, four dimensions).



Figure 1 – Scheme of functionality.

Each sheet is basically formed by the soil map, a set of graphic elements (photos, schemes and tables) and some text that allows understanding the soil characteristics of the territory represented (Figure 2). They are, therefore, self-consistent documents that contain all information necessary for a proper interpretation.

The (1:25.000) soil map is the central element of the sheet and contains all delineations that provide essential information about the main soils types that appear in the area and their spatial distribution. The basic map units are consociations of these main soil types, although complexes are also allowed if it is justified by the soil distribution pattern.

The legend consists of an organized list of the map units that appear on the map. In this case, map units contain the name of the main soil types and their classification according to the Soil Taxonomy system (SSS, 1999) and the Word Reference Base for soil resources (IUSS, 2007).

Soil types have been defined based on the parent material, effective soil depth, drainage class, presence and distribution of diagnostic horizons, texture, presence and composition of rock fragments, concentrations,

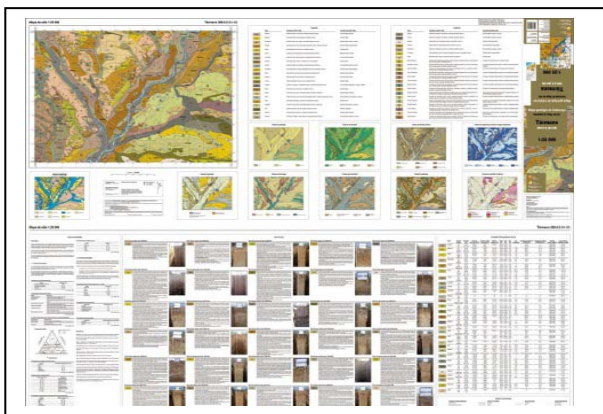


Figure 2 – Sheet 64-28 (Térmens) of the soil map (1:25.000) of Catalonia.

For ease of use, map units have been sorted, simply, alphabetically. Furthermore, it must be noteworthy that, in order to lighten the map legend, it does not explicitly list the phases of the map units, although they are included in the associated soil information system.

Complementary maps and schemes are included in the soil map sheets; they are intended to facilitate the interpretation and visualization of important soil characteristics: soil depth, drainage class, underlying material, available water holding capacity and the agrological capacity classes of the soils.

The description of the main soil types provides essential information on their spatial distribution in the territory and their morphological characteristics: soil depth, presence and distribution of different horizons, color, texture, coarse fragments, structure, consistence, soil penetrability, concentrations, cutans, human activity, biological activity...

In addition, in order to get a better understanding of the different soil types that appear in each sheet, all descriptions are accompanied by a picture that tries to illustrate the main characteristics of their morphologies.

A table, summarizing some of the most important chemical (soil reaction, electrical conductivity, organic matter content, calcium carbonate content, cation exchange capacity) and physical (texture, bulk density) characteristics also complements soils descriptions.

Published sheets contain a methodological summary that explains, briefly, how the map has been executed and the technical criteria that have been used in the identification and description of the different soil types and soil map units that shape the soil map. A more detailed document, with the technical specifications required for the

implementation of the ICGC soil mapping programme, can be found on the ICGC website ([www.icgc.cat](http://www.icgc.cat)).

All information collected and generated during the execution of the mapping projects is stored in the corresponding databases and integrated into the soil information system of the ICGC. In this way, storage, edit, processing, analysis, recovery and presentation of the information are enormously facilitated.

The soil catalogue is one of the main products of the soil information system. The creation and maintaining of this catalogue allows soil scientists that participate in the soil mapping programme of the ICGC to access the official and updated collection of the soil types that are applicable to their soil survey areas.

The major items in description of the soil types of the catalogue are: general description, background, distribution and extend, range in characteristics, remarks on diagnostic horizons and features recognized in the pedon, land use, typical pedon and date of latest revision.

The soil map (1:25.000) of Catalonia is available on the website of the ICGC. Individual sheets can be downloaded, in raster format, as soon as the individual maps are published. In the near future, it is intended that all cartographical information is also going to be distributed in vector formats.

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## 3D QUANTIFICATION METHOD OF LINEAR EROSION FORMS ON VINEYARDS USING HIGH RESOLUTION AERIAL IMAGES

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**KEY WORDS:** soil erosion mapping, rill erosion, drone, image processing, edge detection, agricultural practices, soil conservation.

### INTRODUCTION

Switzerland counts with over 15000 ha of vineyards, which represent about 2 % of its total cultivated surface. These wine-producing regions have been increasingly subjected to soil erosion by water since 1950 (Weisshaidinger et al. 2006).

Swiss vineyards are settled on a great variety of parental materials, including silty lateral moraines. Such periglacial deposits are characterized by a high erodibility. Moreover, the high rate of pebbles in the soils developed from this material provokes weak available water capacity (Burgos et al. 2010). As a result, there is controversy over the use of grass cover, which provides soil protection in detriment of water stress due to vegetation concurrence. Besides, climatological needs for the development of late grape varieties constrain their emplacement on upslope areas (Mosimann et al. 1991). Here, the in-rows disposition of vines in the slope direction, and the mechanized land practices introduce on-site linear features concentrating overland flow. Such topographic and human-induced factors lead to an acceleration of soil erosion (Ledermann et al. 2010), where losses may exceed  $15 \text{ t}\cdot\text{ha}^{-1}$  during heavy rainfall all across Swiss regions (Weisshaidinger et al. 2006). Thus, a compromise must be reached among water concurrence, which is generally related to undesirable flavours in wine, the minimisation of production costs, and the adoption of soil conservation practices.

The periodicity that characterizes the lined-up culture of vines multiplies the occurrence of linear erosion forms. Hence, the proper field mapping of an erosion event demands high investment of time and human resources, which may be subject to considerable error. Therefore, an automatized procedure to quantify and record erosion rills would provide not only an efficient way to assess erosion, but also reliable quantification of soil losses.

### OBJECTIVES

This work aims at finding an automatized method for mapping and quantifying linear erosion forms on high-risk areas using high-resolution aerial images. Such target settles three main computational challenges:

- The reconstruction of a Digital Terrain Model (DTM) prior to the erosion event.
- The establishment of a general procedure to effectively process images.
- The final calculation of the eroded volume.

Data from aerial photos is to be validated against field surveys, carried out at the same time as the aerial prospection.

### MATERIALS AND METHODS

Erosion onsite effects were recorded by means of an Unmanned Aerial Vehicle (UAV), commonly known as drone, which was obtained from Sensefly (eBee, EB-02 series). Images were taken with a Canon S110 camera, and pixel resolution was set at 3 cm, corresponding to a flight height of 85 m above ground. Images were taken during the dormancy stage of vines in Geneva Region. They were assembled on Pix4DMapper software, so as to obtain an orthorectified image within the RGB spectrum, and a reconstructed Digital Surface Model (DSM).

An automatized procedure was developed on Python software, using open source libraries (Scipy, Numpy, Matplotlib), and GIS functionalities (Gdal). This model consisted of two main steps: extraction of rill edges, and volume calculation. The DSM was firstly processed in order to obtain a reference ground level or DTM. The differential model between both layers led to the generation of a no-slope ground where only erosion discontinuities would be detected. Further to the application of smoothing filters, rills were delineated by means of a gradient operator, where zero-crossings were attributed to the rill sinks and edges. Semi-automatized thresholds were chosen according to the spatial variability of each

particular field so as to detect significant surface discontinuities.

Finally, the volume of depleted soil was calculated according to pixel resolution adding up the depths of the selected areas, corresponding to the differential model. Additionally, volume values were reported to mass units by means of soil density. Note that validation of the model was accomplished through several field measurements.

## RESULTS

Prior to quantification, supervised classification of erosion patterns was firstly observed on the RGB images. Here, the presence of erosion rills was correlated with zones depleted of its fine fraction and vegetation, since a higher concentration of pebbles (quartzite, granite) meant higher reflectance (Figure 1). These were coupled with the mechanized passages through vine rows as well.



Figure 1 – Vegetal cover extracted through supervised classification ( $r^2=0.61$  correlation with field prospection)

High-resolution images permitted to obtain an accurate DSM with a mean resolution of 3 cm. An automatized model was successfully developed for the detection of small and large rills (depth <10 cm, and 10<depth<50 cm respectively) in variant scales. The morphology of rills was obtained by accurate delineation of edges on the inflexion points (Figure 2). Finally, the obtained eroded volumes showed a good correlation with the field measurements ( $r^2 = 0.70$ ).

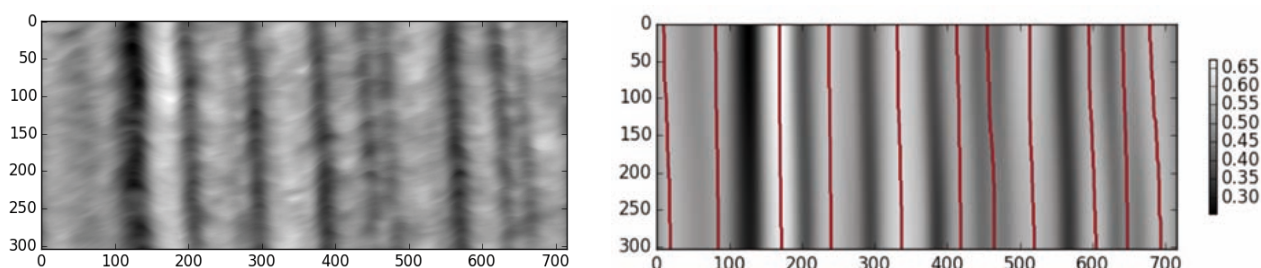


Figure 2 – Wineyard extraction DSM – DTM (left); smoothed model with delimitation of rill edges (right). Normalized altitude values.

## CONCLUSIONS

High-resolution aerial images enable the assessment of linear forms of erosion on steep and heterogeneous landscape. Image processing and geographical information treatment allow the detection of rill edges according to a threshold of inclusion. Due to the high accuracy of images, natural variability of the field surface must be taken into account when settling such delimiting value. The calculation model here obtained provides soil erosion values in accordance with real field measurements. Moreover, the validation of computed values was accomplished despite the precision with which pixel values are located. Eventually, the resulting model may provide erosion assessment in terms of prevention practices, at the scale of each winegrower context.

## ACKNOWLEDGEMENTS

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# SOIL ORGANIC CARBON QUANTIFICATION IN PODZOL SUBSOIL AS AN ATTEMPT TO REFINE SOIL CARBON INVENTORIES IN THE CZECH REPUBLIC

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**KEY WORDS:** *carbic podzol, soil carbon density, Bhs horizon, visualisation, subsoil.*

## INTRODUCTION

As far as we know that soil are important sink of carbon, an attempt to quantify the carbon stock and fluxes exists.

Organic horizons are homogenous in terms of carbon content (Dégórski 2007; Liski and Westman 1997), therefore the quantification of the soil carbon density in organic horizons is quite simple. However, the carbon density is often underestimated by exclusion of mineral horizons deeper than 30 cm, which can be rich in carbon as well. It is the case not only the chernozems, and fluvisols. According to Rumpel et al. (2002) the soil organic carbon in mineral subsoil can be up to 47% in some cambisols, in podzols up to 75%. Podzols are significant of having high soil carbon stock in their subsoil (subsurface mineral horizons) but this stock has high variability in its spatial distribution; the variation coefficient can be up to 146% (Batjes 2002).

Soil carbon quantification is quite common in the world, for example Batjes (1996, 2002) or Schwartz and Namri (2002). The quantification of soil carbon in forest soil in CZ project was carried out for the upper 30 cm, which is, considered by Marek et al. (2011), crucial for the soil carbon balance. The only currently available output on a national level with soil carbon data in CZ is the map with charts of the soil carbon stock in Marek et al. (2011). However, the map does not represent the real soil carbon stock, due to exclusion mineral subsoil deeper than 30 cm from quantification. A considerable amount of carbon can be accumulated deeper than 30 cm: in case of podzols up to 66% according to Batjes (2002) or up to 75% according to Rumpel et al. (2002).

Therefore, the aim of this study is to make an attempt to refine carbon quantification in soil in the Czech Republic by including subsoil. For this purpose, a profile of Carbic Podzol (IUSS WRB, 2007) was chosen. The emphasis was put on soil carbon density in the subsoil and its visualisation.

## METHODS AND STUDY AREA

Ralsko region in the Czech Republic (CZ) is known as locality with well-developed Carbic

Podzols. The underlying bedrock is thick-bedded sandstone. Studied pedon (visualised in Fig. 1) was chosen as representative of Carbic Podzol both in Ralsko and CZ. Tonguing of Bhs horizon is frequent in the locality.

Soil samples for carbon and bulk density (BD) estimation were taken from centres of all horizons. More samples (7) were taken from Bhs horizon because of local presence of the ortstein in this horizon. Soil organic carbon was estimated by modified Tjurin method. Calculation of soil organic carbon density was taken according to Cienciala et al. (2006) for each horizon:

$$SOC = C_{ox} \times BD \times T \times CF \times 10 \quad (Eq. 1)$$

where  $SOC$  is the final soil carbon density ( $kg\ m^{-2}$ ) in horizon,  $C_{ox}$  is the soil carbon content (%),  $BD$  is the bulk density ( $g\ cm^{-3}$ ),  $T$  is the thickness of the horizon (m) and  $CF$  is the coefficient for estimation of coarse fragments (absent coarse fragments,  $CF = 1$ ). Similarly, see Batjes (1996) and Schwartz and Namri (2002).

Dataset of soil carbon densities for each horizon was put into a grid by kriging. The courses of the carbon in individual soil profiles in the studied pedon were visualised as a diagram of soil carbon density in individual horizons (Fig. 2 for example). Additionally, the spatial variability of all horizon courses (Fig. 1) was visualised.

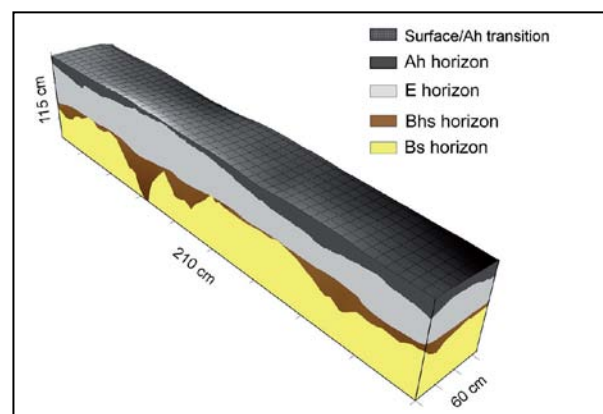


Figure 1 – Scheme of studied pedon stratigraphy.



## RESULTS AND CONCLUSION

The course of the carbon densities in individual horizons and in the whole profile is depicted in Figure 2. The total carbon density depends on horizon thickness. First of all, carbon stock in the whole soil profile is determined mainly by carbon density in Ah horizon, because of the small thickness of Bhs horizon. But, where the tonguing is appearing, and as you can see from Fig 2 it is very frequent in the locality, the total carbon density is considerably affected by higher thickness of Bhs.

The carbon densities were estimated for each horizon separately and for whole pedon, and visualised (not shown). For comparison with the work of Marek et al. (2011) the quantification of carbon densities below and above the level of 30 cm was done (not shown). The exclusion of the mineral or organic horizons below the 30 cm leads to shrinkage of the total carbon density up to 53% (not shown). The total carbon density in whole soil profile is 4.997 kg-2m. The average carbon density is highest in Ah horizon, but a large amount can be found in Bhs horizons. It is a reason why mineral horizons should not be excluded from carbon density estimation.

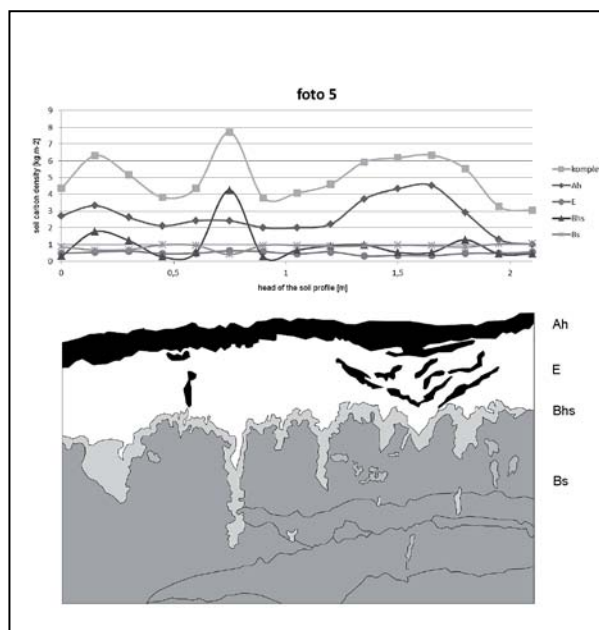


Figure 2 – The course of soil carbon densities in each horizon and in whole soil profile (“komplet”).

## ACKNOWLEDGEMENTS

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## PROTECTION WORKS AGAINST THE EROSION OF THE COASTS NEAR TO TORRE OVO IN CAMPOMARINO DI MARUGGIO (TA)

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**KEY WORDS:** *Torre Ovo, Campomarino erosion, petrified fossil forest, The Tower, natural morphology.*

The recommendations of the plan foresee the realization of a close protection work : limestone cliff with rocks of appropriate weight in order to redraw the coastline of the cliff with the aim to obtain a natural morphology compliant with the environment .

### ABSTRACT

During the preparation of the municipal plan of the coasts (PCC) of Maruggio in Taranto province, following the guidelines of the Regional Plan of the Coasts (PRG), the geological study of the Ionian coasts of Campomarino, near the Tower Ovo " Torre Ovo" was deepened, because subject to erosion and therefore necessitating of protection works. Torre Ovo is the base of an ancient Greek - Roman port of the IV sec a.C. and of the famous "petrified fossil forest".

The study ,after a meteo-marine classification of the area and a detailed geological and geotechnical analysis, examines what might be the most effective works suitable to mitigate the erosion process and the effects that such choice induces on the surrounding environment in terms of geomorphological alteration and environmental impact

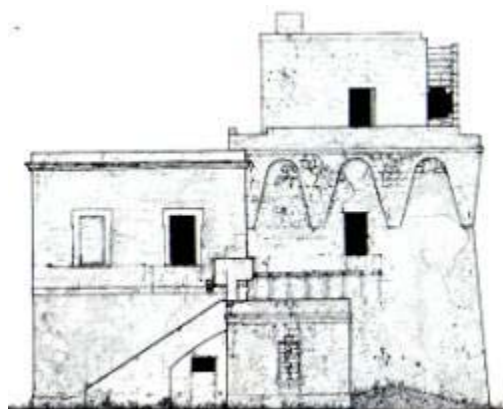


Figure 1 Torre Ovo.

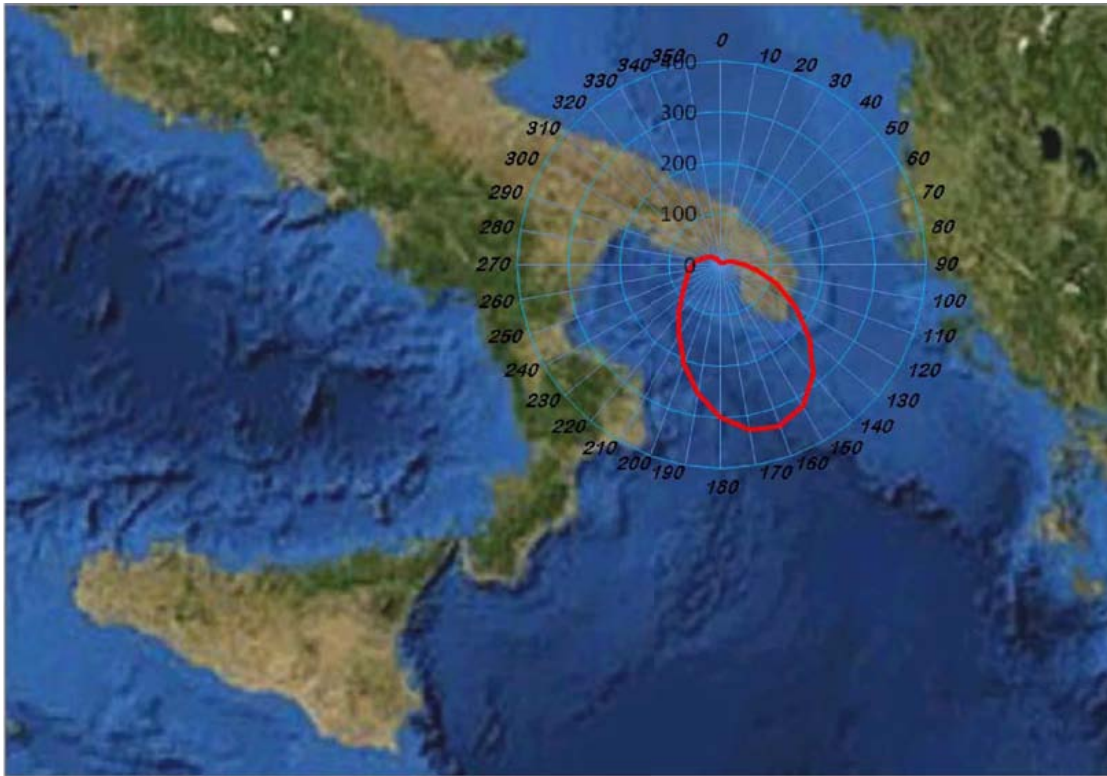


Figure 2. Fetch effective off Torre Ovo in point coordinates  $N^{\circ} 40 285 - 17 475^{\circ} E$ .

The area surrounding the tower, once safe, can be accessible and enhanced thanks to the geological characteristics of the "fossil forest". The marine geological site is important either because it is constituted by burrows built by bivalves, gastropods, rudists, etc., probably during the Calabrian, and discovered by the abrasive action of the sea, or because it marks the transition between the Pleistocene "panchina" type calcarenites and the recent gray-yellowish sands, or because of the historical importance of the Roman port, now submerged, and the Tower itself.

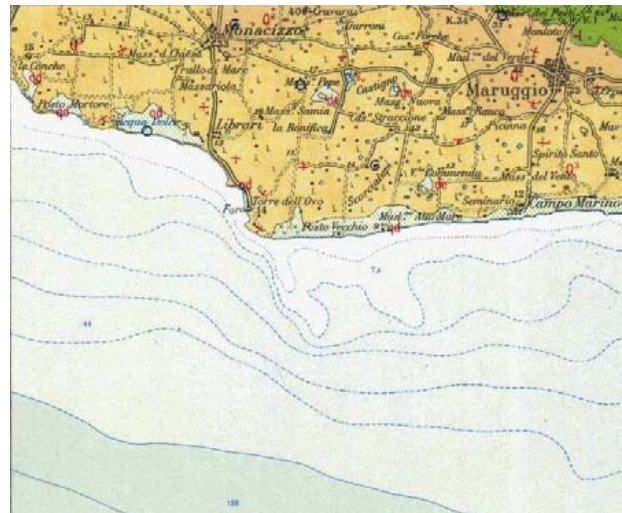


Figure 3. Excerpt from the Geological Map - 213 sheet.



Figure 4. Cliff, erosion landform, near Torre Ovo.

For its size, use, history over the centuries (Giaccari, 2000), and its overhanging position on the sea, easily visible from all over the surrounding coastline, the Tower of the Kingdom of Naples has characterized the site, so that the surrounding coast took his name and represents the symbol of the stretch of coastline. It has also served as lighthouse for both military and civil scopes.

Therefore an appropriate intervention of coast protection, respectful of the geomorphological context, can enhance the area, that represents an important site for scientific and humanistic studies.



Figure 5. Photos Torre Ovo.

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# CARTOGRAPHIC TOOLS TO SUPPORT THE MANAGEMENT OF CONTAMINATED SITES: THE “PEDOGEOCHEMICAL MAPS AT 1:250.000 SCALE” OF EMILIA-ROMAGNA REGION.

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**KEY WORDS:** heavy metal, soil, background content, pedogeochemical content contamination.

## INTRODUCTION

About organic compounds and heavy metals in soils the Italian Legislative Decree 152/06 of April 3<sup>d</sup> allows to replace the threshold values by using background values (art.240, comma1, letter b).

These latter ones are always in soils as trace elements, whose content is controlled by: parent material texture and weathering in the topsoil control factors are also organic matter content and land use, which represent the part of the anthropogenic impact.

## BACKGROUND VALUE

To assess the state of contamination of a site the natural and anthropogenic contribution to the background value of the the outside that is near or around the site” must be defined

This enables to better apply the “site-specific environmental health risk assessment” and to optimize the detailed operations to characterize the site.

As far as Italy concern the legislation doesn't provide guidelines on the determination of background values, except for the large contaminated sites at national scale (APAT, ISSDS 2006) where a procedure is identified, which takes into account all the existing useful information.

For soil the European standard ISO 19258:2005 is the reference.

## MATERIALS AND METHODS

The Geological, Seismic and Soil Survey of Regione Emilia-Romagna has produced in the last ten years 13 maps following the standard ISO 19258:2005. The project “Pedogeochemical maps of Emilia-Romagna alluvial plain” includes five maps of the natural content “pedogeochemical value” for Cr, Cu, Ni, Pb, Zn (the sixth –Vanadium- is being drafted) and eight maps of the background value for As, Cr, Cu, Ni, Pb, Sn, V, Zn.

The maps are focused on the plain because of the intense exploitation of this area by agriculture and industrial activities

The dataset includes topsoil (samples at 20-30cm depth) and subsoil (samples at 90-130 cm)

Unit	Diagnostic features		Environmental features
Code	Soil	Sediment provenance	Depositional environment
A1	Medium to fine-textured, high degree of weathering <i>Stagnic Luvisols, Vertic Cambisols</i>	Mixed (from Apenninic sources with extremely variable ophiolitic contribution)	Alluvial fan, interfluvial terrace (indifferentiated)
A2	Fine-textured, low to moderate degree of weathering <i>Vertic Cambisols, Hyposalic Vertisols, Calcic Vertisols</i>	Apenninic sources, with no ophiolitic contribution	Alluvial plain Floodplain deposits
A3	Fine-textured, low to moderate degree of weathering <i>Vertic Cambisols, Calcic Vertisols, Eutric Vertisols</i>	Mixed Po-Apenninic sources, with moderate to high ophiolitic contribution	Alluvial plain Floodplain deposits
A4	Fine-textured, low to moderate degree of weathering <i>Vertic Cambisols, Calcic Vertisols, Hyposalic Vertisols</i>	Po River	Delta (delta plain) Interdistributary area deposits
B1	Moderately fine-textured to moderately coarse-textured, with rare gravels, low to moderate degree of weathering <i>Haplic Cambisols, Haplic Calcisols</i>	Apenninic sources, with no ophiolitic contribution	Alluvial plain and alluvial fan Channel-levee and crevasse deposits
B2	Moderately fine-textured to moderately coarse-textured, with rare gravels, low to moderate degree of weathering <i>Haplic Cambisols, Haplic Calcisols</i>	Mixed (mostly from Apenninic sources, with moderate ophiolitic contribution: Enza, Baganza and Tresinaro rivers)	Alluvial plain and alluvial fan Channel-levee and crevasse deposits
B3	Moderately fine-grained to moderately coarse-textured, with rare gravels, low to moderate degree of weathering <i>Haplic Cambisols, Haplic Calcisols</i>	Apenninic sources, with moderate to high ophiolitic contribution (Arda and Taro rivers)	Alluvial plain and alluvial fan Channel-levee and crevasse deposits
B4	Medium to moderately coarse-textured, low to moderate degree of weathering <i>Haplic Cambisols, Haplic Calcisols</i>	Po River	Alluvial plain and alluvial fan Channel-levee and crevasse deposits
B5	Moderately fine-grained to moderately coarse-textured, with abundant gravels, low to moderate degree of weathering <i>Haplic Cambisols, Haplic Calcisols</i>	Apenninic sources, with high ophiolitic contribution (Trebbeia and Nure rivers)	Alluvial plain and alluvial fan Channel-levee and crevasse deposits
B6	Medium to moderately coarse-textured, low to moderate degree of weathering <i>Haplic Cambisols, Haplic Calcisols</i>	Po River	Delta (delta plain) Distributary channel-levee and crevasse deposits
C1	Coarse-textured, low degree of weathering <i>Endogleyic Arenosols</i>	Apenninic sources, with no ophiolitic contribution	Coastal plain Beach-ridge deposits
C2	Coarse-textured, low degree of weathering <i>Endogleyic Arenosols</i>	Po River	Delta (delta front) Beach-ridge deposits

**Table 1 – Pedological and geological features of the Genetical-Functional units (GFUs) that form the Pedogeochemical Map of the Emilia-Romagna plain (WRB, 2006).**

analyses from 700 sampling sites in agricultural soils. The selection of sampling sites was carried out following the “typological approach” thus on the base of different georeferenced information layers mainly the soil map at 1:50.000 scale.

Different analytical methods have been applied for the two maps: for the pedogeochemical map X-Ray Fluorescence data have been used because they better depict the genetic content whereas for the map of the background content aqua-regia

extraction data (UNIEN 13346+EPA 6020) have been used to allow the comparison with the majority of the environmental data already available at regional and national scale.

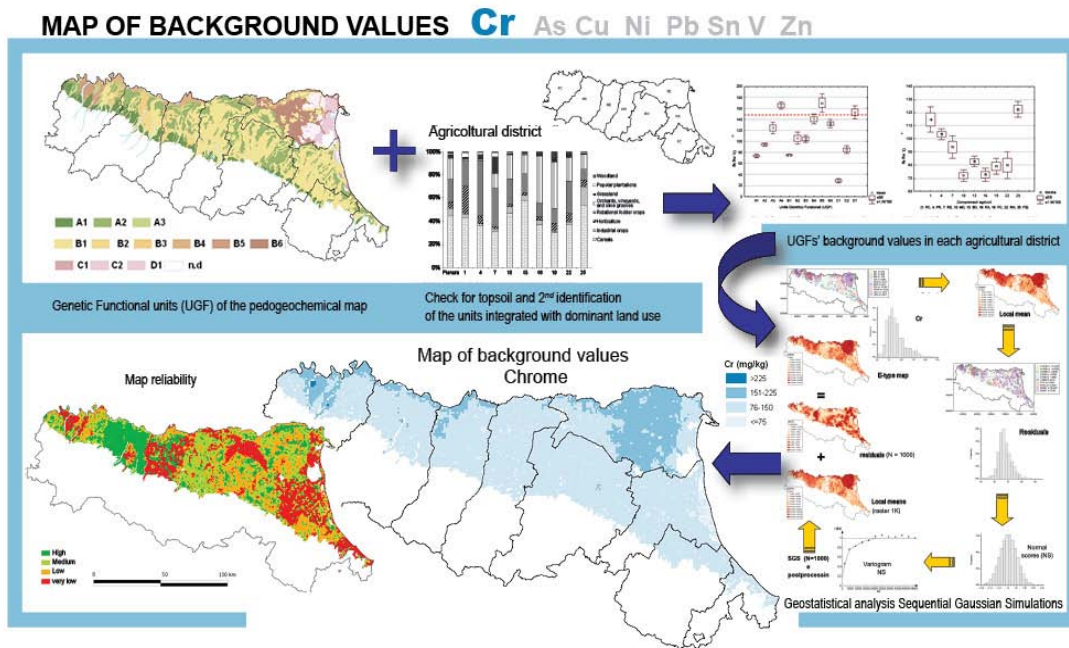


Figure 1 Infographic of the background map. Chrome example

## RESULTS

The course of the research started from the genetic stock which determines the pedogeochemical content identified through pedological, geological geomorphological and

bibliographic studies and carried on with the land use analysis to describe the background content.

The result is the Map of the background content. By supplying a scientifically correct frame, the Map takes into account local peculiarities and increases the accuracy in soil contamination evaluating.

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## APPARENT SOIL ELECTRICAL CONDUCTIVITY AND NDVI TO DELINEATE MANAGEMENT ZONES IN FRUIT ORCHARDS

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**KEY WORDS:** *Proximal sensing, precision agriculture, ECa mapping, clustering*

### INTRODUCTION

Apparent soil electrical conductivity (ECa) is a quick, reliable, easy-to-take soil measurement that is widely accepted as a means to analyze the spatial variability of several soil physico-chemical properties that influence crop yield (Corwin & Lesch, 2006). For these reasons, the measurement of ECa is at present one relevant tool in precision agriculture. The objective of this work is to compare the delineation of management zones in a fruit orchard on the basis of ECa measurements alone and in combination to high resolution NDVI images.

### MATERIAL AND METHODS

The study was carried out in Gimenells (Lleida, Catalonia, Spain), in a *Prunus persica* var. *platycarpa* orchard of 0.65 ha located at the IRTA Experimental Station (Long 0.392017, Lat. 41.654413). The orchard has a plantation pattern of 5 x 2.80 m. The soil is well drained, without salinity problems. Soils are classified as Petrocalcic Calcixerept (Soil Survey Staff, 2014), with a petrocalcic horizon at a variable depth of 40–80 cm. This limiting horizon has been broken over time by tillage operations on zones that appear shallower.

An aerial survey was carried out with the Atmos-6 UAV drone and a VEGCAM-Pro camera (CATUAV, Moià, Catalonia, Spain). The survey took place on 30/06/2014. The images were acquired in three wide spectral bands: green (525–575 nm), red (615–685 nm) and near infrared (755–805 nm), with a radiometric resolution of 8 bits/pixel. They were rectified and mosaicked with the aid of the software Pix4D (Pix4D SA, Lausanne, Switzerland), producing images at a spatial resolution of 0.15 m. Using the reflectance values the NDVI (Normalized Difference Vegetation Index) (Rouse et al., 1974) was computed (Figure 1A).

The ECa was measured by means of the sensor Veris 3100 EC Mapping (Veris Technologies Inc., Salina, KS, USA). It works injecting electrical current into the soil by a pair of coulter-electrodes, while two other pairs of coulter-electrodes measure the voltage drop at 0–30 cm (shallow ECa) and 0–90 cm (deep ECa). The sensor was connected to a Trimble AgGPS332 with differential correction SBAS (satellite-Based Augmentation System) based on EGNOS, which associated GPS to the measurements. The survey was carried out on 23/03/2015, acquiring a total of 644 measurements along the orchard rows (density of 990 points/ha). The ECa measurements were interpolated to a 0.5 m grid by means of ordinary kriging using exponential semivariograms with ArcGIS 10.3 for Desktop and Geostatistical Analyst (ESRI Inc., Redlands, CA, USA) (Figure 1 B and C).

Two types of management zones were delineated using the ISODATA algorithm implemented in ArcGIS 10.3. It is a k-means algorithm that uses minimum Euclidean distance to assign a cluster to each candidate pixel in an iterative process (Jensen, 1996). In the first case two zones were delineated using the Shallow ECa and the Deep EC. In the second case, the NDVI was added and the three variables were considered to produce a two-zone map. Before applying the ISODATA algorithm, the three variables were normalized. Finally, a Tukey's range test using JMP Pro 11.0.0 (SAS Institute Inc., Cary, NC, USA) was applied to compare the means of the NDVI in the delineated management zones.

### RESULTS AND CONCLUSIONS

Figure 2 shows the zones delineated with the Isodata algorithm and Table 1 presents the means of the variables in each zone.

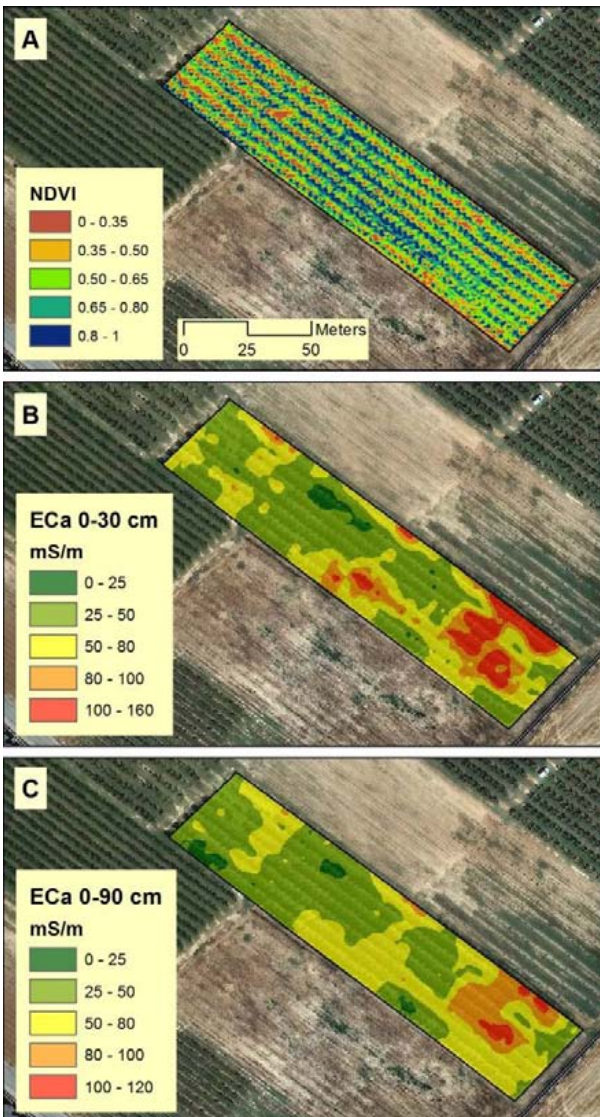


Figure 1 – A) NDVI map derived from the drone image; B) Shallow (0-30 cm) ECa map and C) Deep (0-90 cm) ECa map.

Table 1 – Mean and standard deviation of ECa and NDVI in the delineated management zones (A and B correspond to the situations in Figure 2)

Zones	Shallow ECa mS/m		Deep ECa mS/m		NDVI	
	Mean	SD	Mean	SD	Mean	SD
1A	42.61	10.8	42.75	9.67	0.593	0.202
2A	87.11	18.94	74.12	14.82	0.64	0.173
1B	42.23	10.47	42.63	9.34	0.599	0.201
2B	86.09	19.32	73.59	14.75	0.628	0.18

In both cases, the means of the variables are different with a p-value <0.0001

These results indicate that the NDVI did not provide relevant additional information to the zoning with the ECa variables. In addition, in both cases the NDVI presented statistically significant different means, which indicates the relation

between ECa and NDVI. In the present case study the zones with high ECa and higher NDVI corresponded to deeper soils in the orchard field.



Figure 2 – Comparison of management zones delineated with the Isodata algorithm A) Shallow (0-30 cm) and Deep (0-90 cm) ECa and B) with both ECa variables plus the NDVI.

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## HYDRIC SOILS: MAPPING AND CLASSIFICATION

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**KEY WORDS:** *Hydric soils, Soil Taxonomy, cartography.*

### INTRODUCTION

Wetlands are high valuable areas that occupy an area between 8 to 10 million km<sup>2</sup> worldwide (Mitsch and Gosselink, 2007). It is necessary, therefore, to define them cartographically as natural or agricultural areas. Hydric soils show specific characteristics that have been researched in the last decades as a new soil class with a permanent or semi-permanent water layer on or near the surface. The special characteristics in soil formation: presence of water, specific geomorphology, vegetation, geologic material, etc., make hydric soils more difficult than regular soils for describing, sampling and mapping. In a normal soil survey, the scientists define the homogeneous soil units with photogrammetry and photointerpretation (Soil Survey Staff, 1966), and after that, they define the soil profiles for classification. However, problems arise when the geomorphology and geologic material in the area are the same and this methodology cannot be used. In that case, other factors such as organic matter, carbonates, salinity, and so on, can differentiate soil units, which is the basis of any soil classification study.

In wetland areas, especially in coastal wetlands, there are several problems in the first step of soil classification because scientists usually recognise the whole area as a single soil unit. However, soil properties, which cannot be recognised visually, can help to delineate different soil units.

This problem was found in one of the most important wetlands in Spain, the Albufera of Valencia. To solve that situation, a GIS-based protocol for automatically mapping the different soil homogeneous units according to the Soil Taxonomy criteria has been developed in this study with the aid of geostatistical methods.

### METHODOLOGY

The Albufera of Valencia is a wetland that covers a marsh area of 15.500 ha cultivated with rice. The use of classical photointerpretation techniques was impossible due to the micro-

morphology and the geological material which resulted in the definition of a single homogeneous unit of soil. To solve that problem, a systematic soil sampling process was designed in a radial net around the lagoon. A set of 133 soil pits were defined and georeferenced in three dimensions with GPS equipment using the virtual reference station (VRS) technique (Figure 1). The instrument used was a Leica GPS 1200 receiver that supplied UTM coordinates together with elevations above sea level. Those pits were sampled with a spiral auger at 0-20, 20-40, 40-60, 60-80 and 80-100 cm. Later, soil samples were analysed according to USDA methodologies (Soil Survey Staff, 2009). Salinity, organic carbon, texture, carbonates, water capacity, colour, pH and main cations and anions were determined in the laboratory, whereas other variables such as structure, aqic condition, redox features, or roots, were defined in the field.

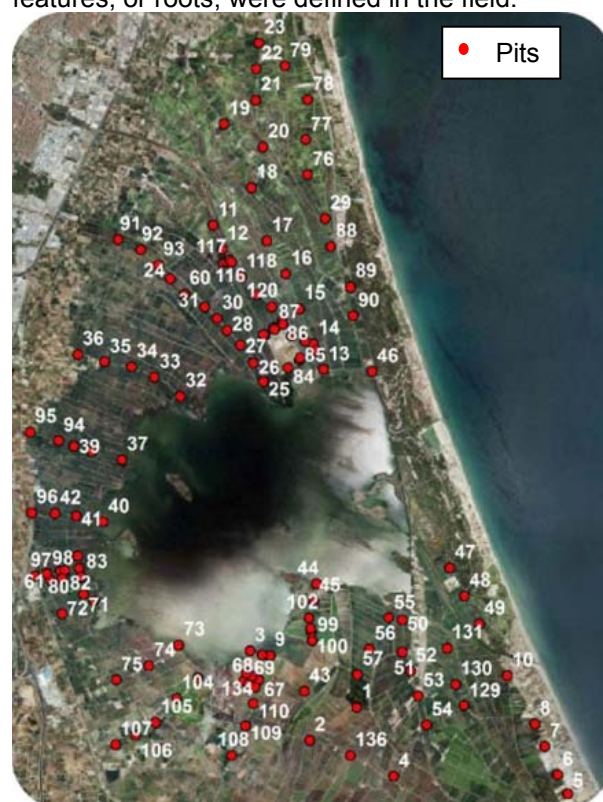


Figure 1 – Soil pits

Once the soil samples were analysed, the outcomes at different depths were interpolated using the Bayesian Maximum Entropy (BME)

method. The interpolation of each variable produced five layers (one each 20 cm) that were automatically summarised into a single binary layer with two categories corresponding to pixels that met the taxonomic criteria and pixels that did not (Figure 2). Soil units were then defined and soil profiles were identified for description and classification purposes. In the next step, Soil

profile samples were analysed and soils were classified according to the Keys to Soil Taxonomy (Soil Survey Staff, 2014). Once the soil profiles were defined, a soil map was created and all the soils in the area were classified for future studies. All the mapping data were processed within ArcGIS 9.3.

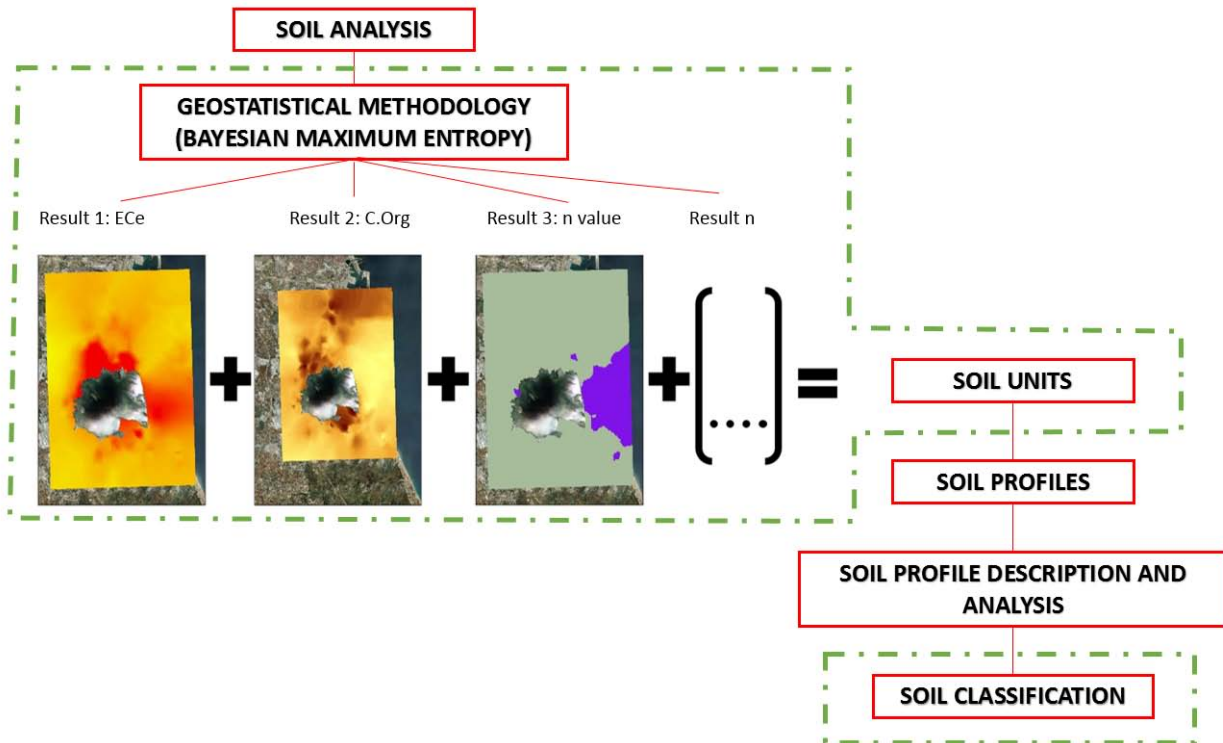


Figure 2 – Scheme of protocol process

## RESULTS AND CONCLUSIONS

Hydric soils showed spatial differences based on their intrinsic properties that could not be detected with the study of forming factors. The methodology developed in the study allowed us to define 6 soil classes in contrast to the single class recognized in older studies. In this regard, the combination of geostatistical techniques, together with a good soil sample design, made it possible to define soil units and profiles in a wetland area where the classical soil survey process could not be applied.

A set of 45 map layers representing different soil properties was generated with the BME application. The combinations of those maps allowed us to locate 19 soil profiles for description, analysis and classification purposes. After that process, a soil classification map was created with the special feature that it encompassed all the soil types in the wetland area.

It is clear that the sampling process had a high cost, but the aim of this study was to check the protocol, so a big set of data was needed. In this regard, indirect methodologies like TDR sensors or

salinity sensors can be used in future studies for reducing costs. Likewise, the number of sample points required for classifying correctly hydric soils in wetland areas should be further studied in order to define the minimum quantity of sample pits that gives satisfactory outcomes.

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## REVISION OF SOIL INDICATOR CS015 FOR THE MANAGEMENT OF CONTAMINATED SITES IN EUROPE

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**KEY WORDS:** Contaminated sites, indicators, industrial chemicals, priority, risk assessment, environment, human health.

### ABSTRACT

This paper illustrates the progress with the management of contaminated sites in Europe. It identifies local soil contamination as an important threat to human health and ecosystems. It aims to inform policy makers, professional practitioners, researchers, citizens and the media on the various Directives and projects related to soil protection. This paper is based on the JRC Reference Report "Progress in the management of contaminated sites in Europe" where data were collected from the National Reference Centres for Soil in 39 countries belonging to the European Environment Information and Observation Network (EIONET) during a campaign organised by the JRC European Soil Data Centre in 2011-2012. A set of indicators contributes to the Core Set Indicator "Progress in the Management of Contaminated Sites" (CSI 015) of the European Environment Agency (EEA), which is used for reporting on the State of the Environment.

### EUROPEAN LEGISLATION AND SOIL PROTECTION

European environmental policy is one of the policy areas mostly developed since the last decade. It is well recognised that environmental problems go beyond national and regional borders and can only be resolved through collective actions at EU and international level. From an initial focus on chemical pollutants and impacts, environmental policy is moving into an integration phase, with the emphasis on understanding and

addressing the pressures on the environment and examining the effects of different policies and behaviour patterns. Priorities have been set for water, air, waste, and chemicals where several Directives and Regulations have been implemented in Europe. However Water Framework Directive, Waste, Industrial Emissions and Landfill Directives, REACH and CLP Regulations of chemicals do not address all the soil threats in a comprehensive way and not all Member States have specific legislation on soil protection. Article 191(2) of the Treaty on the Functioning of the European Union (TFEU), Union policy on the environment aims at a high level of protection taking into account the diversity of situations in the various regions of the Union, and is based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should, as a priority, be rectified at source and that the polluter should pay.



Figure 1 – European Legislation related to the protection of the soil environment.

The Soil Thematic Strategy explains why further action is needed to ensure a high level of soil protection; it sets the overall objective of the Strategy and describes what kind of measures must be taken.

Because not only do biodiversity loss and the degradation of ecosystems in the Union have important implications for the environment and human well-being, they also have impacts on future generations and are costly for society as a whole, particularly for economic actors in sectors that depend directly on ecosystem services. Its overall objective is the protection of soil functions and sustainable use of soil, based on two guiding principles:

- Prevention of soil degradation
- Restoration of degraded soils

The EU Commission released a report (2012) on implementation of the Soil Thematic Strategy and on-going activities which presents the current soil degradation trends both in Europe and globally, as well as future actions needed to ensure its protection.

On May 2014 the European Commission has withdrawn the proposal for a Soil Framework Directive (SFD), REFIT Communication COM(2013) 685, 2.10.2013. Nevertheless, the Commission remains committed to the objective of the protection of soil and will examine options on how to best achieve this. It has launched in 2015 a study on Soil legislation and policy instruments with lessons learnt exercise from the SFD and a revision of the gap analysis and options on how to best achieve soil protection based on proportionality and subsidiarity principles.

### REVISION OF THE INDICATOR 'PROGRESS IN MANAGEMENT OF CONTAMINATED SITES'

The report on "Progress in the management of Contaminated Sites in Europe" presents the current state of knowledge about progress with the management of contaminated sites in Europe. It directly supports the EU Soil Thematic Strategy

(COM(2006) 231), which identifies local soil contamination as an important issue. It presents facts, analyses and methods on the management of Contaminated Sites, which can inform policy makers, professional practitioners, researchers, citizens and the media.



The information presented in this report is based on a set of indicators which have been agreed on and used by the EIONET for more than a decade. This set of indicators contributes to the Core Set Indicator "Progress in the Management of Contaminated Sites" (CSI 015) of the European Environment Agency (EEA), which is used for reporting on the State of the Environment.

The indicator 'Progress in management of contaminated sites' (LSI 003/former CSI 015) is part of the thematic cluster 'Land & soil indicators' (LSIs) (see the table below presenting existing indicators and indicators under development). This cluster has been created to give greater visibility to the land and soil indicators.

### Thematic cluster 'Land & soil indicators' (LSIs) Existing and under development

Indicator code	Indicator name	Update/Comments
LSI 001/CSI 014	Land take	Following CLC updates, every 6 years
LSI 002	Imperviousness/Soil sealing	Following HRL updated, every 3 years – first publication in 2015
LSI 003*	Progress in management of contaminated sites	To be revised to increase comparability across countries
LSI 004/CSI xxx	Fragmentation of habitats and ecosystems	Under development
Ct. GEEI 013*	Fragmentation of semi-natural areas	Assessment published May 2010; update expected Q1/2015 (CLC 2006)
LSI 005/CLIM 027*	Soil organic carbon	
LSI 006/CLIM 028*	Soil erosion	Ideally following EEA climate change impact indicator reporting cycle, every four years
LSI 007/CLIM 029	Soil moisture	

\* Produced in cooperation with EC-JRC

No legal standards for soil quality have been set at the EU level but targets have been set by some EEA Member countries. The existing EU legislation (Integrated Pollution and Prevention Control Directive (IPPC), Industrial Emissions Directive (IED), Land-field Directive (LD) aims at preventing new contamination and sets targets for the remediation of sites where environmental standards have already exceeded. However a harmonised approach to setting environmental standards for soil quality will facilitate the comparison of data among countries.

At present the EIONET NRC Soil is discussing the revision of the CS015 indicator and the proposal will be presented at the October 2015 meeting in Copenhagen.

## ACKNOWLEDGEMENTS

We are grateful to the EIONET NRC Soil experts who have contributed with data to make possible the publication "Progress in the management of contaminated sites in Europe" (2014).

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ESDAC – European Soil Data Centre  
<http://esdac.jrc.ec.europa.eu/>

## MAPPING SOIL ORGANIC CARBON CONTENT USING SPECTROSCOPIC DATA

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**KEY WORDS:** *Spatial Statistics, FTIR-ATR, Random Forest, Partial Least Squares Regression.*

### INTRODUCTION

To establish rapid methods for mapping soil organic carbon (SOC) contents along extensive areas is still a challenge. Over the past few decades, Digital Soil Mapping has been used to predict soil attributes and describe the spatial distribution of SOC using approaches like Multiple Linear Regression, Kriging, co-Kriging, Regression Kriging and Geographically Weighted Regression (Kumar et al., 2012; Liu et al., 2015). Recent studies have proved the potential of another statistical methods, such as Support Vector Regression, Artificial Neural Networks, Random Forest and Partial Least Squares Regression, to estimate and map SOC contents (Grimm et al., 2008; Rodríguez-Lado and Martínez-Cortizas, 2015; Were et al., 2015).

Traditional laboratory techniques used to measure SOC are time-consuming and relatively expensive. Infrared spectroscopy appears as an alternate technique to estimate SOC in a fast and cheap fashion. In this sense, many authors derived statistical models to predict SOC from spectroscopic data (Viscarra et al., 2006; Soriano-Disla et al., 2014). The main difficulty of this technique is to determine the specific bands that store relevant information on the SOC content. Statistical algorithms, such as Random Forest model, permit the identification of such influential bands explaining most of the variability in SOC, thus increasing the accuracy of the predictive models created (Knox et al., 2015).

Studies at present showed the ability of spectroscopic data to create predictive models of soil parameters at plot scale. However, further research was needed to generalize the information from such models to large spatial scales. This study provides a methodology to parse the relationships FTIR-ATR and SOC from the plot scale to a regional scale in order to map SOC

content in soil epipedons. The objectives of this study are the following:

- To identify the relevant bands of FTIR-ATR data providing information on the SOC concentrations.
- To make use of multivariate statistical techniques (PLS) to map the spatial distribution of these bands in relation to the spatial variability of a number of easily accessible environmental covariates.
- To create a map of SOC in Galicia (NW-Spain) using the formerly described relationships.

### METHODOLOGY

SOC content was determined in 221 topsoil samples collected in Galicia (NW Spain) using the standard Walkley-Black (WB) analytical method. In addition, FTIR-ATR spectroscopic data was measured upon the same set of samples. A set of statistical analyses were performed on these data in order to identify the bands of the spectroscopic signal storing important information to predict SOC at plot scale, to generalize these bands to the regional scale and to map SOC content in the study area. Figure 1 summarizes the statistical steps used within in this study and the goodness-of-fit (R-squared) at each statistical step.

A Random Forest (RF) model, linking WB-SOC and FTIR-ATR data, was used to identify the relevant wavenumbers capturing most of the variability on SOC in our samples. This model showed that a few wavenumbers, placed around 2127, 1705 and 1296  $\text{cm}^{-1}$  can be used to model SOC content. We used Partial Least Squares (PLS) to determine the relationships between the values of the selected wavenumbers and a set of environmental conditions (climate, land use and geology). This permits to create maps depicting estimated values of the relevant wavenumbers at a regional scale. A linear regression model (LM), relating SOC as the dependent variable and the relevant FTIR-ATR wavenumbers, formerly selected, as independent proxies, showed a good predictive performance (R-squared = 0.93; RSME = 1.74; ME = 0.39). We used this linear model, together with the wavenumber rasters obtained by

PLS, to generalize the predictions of SOC in the whole study area.

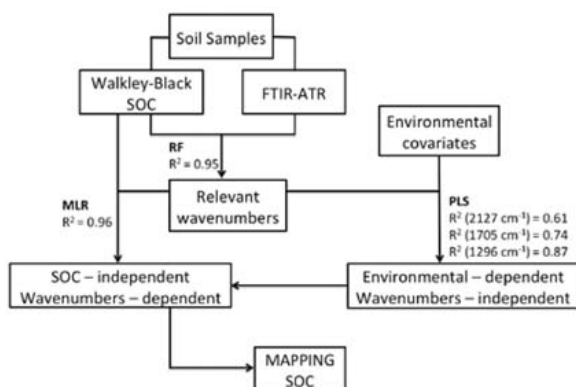


Figure 1 – Diagram showing the steps used to predict and map SOC contents from FTIR-ATR data and the goodness-of-fit of each statistical analyses in the procedure.

## RESULTS AND CONCLUSIONS

The final output from this methodology is a map showing the distribution of SOC content based exclusively on spectroscopic measurements (Figure 2).

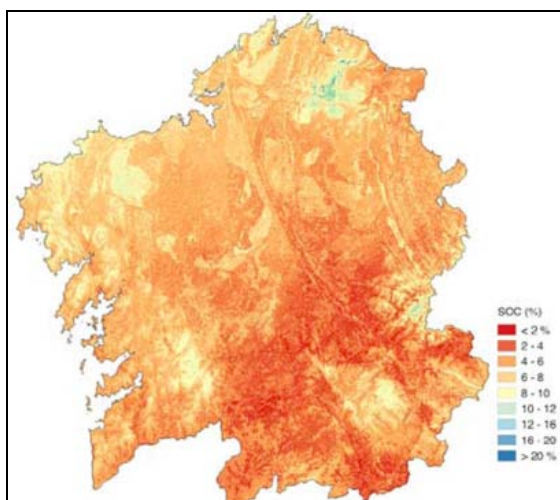


Figure 2 – Predictive map of SOC using FTIR-ATR measurements.

We have developed a complete methodology to estimate and map SOC contents using a short selection of bands from the FTIR-ATR spectra and a number of environmental proxies. The goodness-of-fit the model here developed demonstrates the ability of FTIR-ATR data to capture the variability in SOC contents at plot scale. In addition, the relevant spectroscopic data to explain SOC content is highly correlated to a selection of environmental proxies in the form of raster maps. This correlation can be then used to map SOC contents in topsoil at regional scale. The

relationships between these bands and environmental parameters show that soil moisture, estimated from the monthly water balance, is an environmental parameter that highly influences SOC content. This methodology can be applied in projects with limited time and budget constraints to perform a quick evaluation of the SOC stocks.

## ACKNOWLEDGEMENTS

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## SOIL EROSION FROM MODELLING TO MITIGATION: CAN CONSERVATION AGRICULTURE BE A SOLUTION?

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**KEY WORDS:** soil erosion, soil map, conservation agriculture, soil protection, RUSLE, Life HelpSoil, Visual Soil Assessment, no till.

C = Soil Cover Factor  
P = Support Practice Factor

### INTRODUCTION

The Emilia-Romagna Region has half of its territory occupied by the Apennines chain, which stands along the entire Italian peninsula. This part of the Apennines has a geological substrate affected by constitutional instability, which can result either in vulnerability to landslides or in a high erosion risk, mainly where agricultural soils are intensively cultivated.

Since 2006 Emilia-Romagna Government has identified portions of its territory where the soil erosion risk is high, as showed in a specific map at 1:250.000 scale. This map takes into consideration the RUSLE model methodology (Renard et al. 1997) to quantify soil erosion vulnerability. The map was adopted in the framework of Regional Rural Development Programme 2007-2013 (as provided for by Reg (CE) N. 1305/2005), to identify the target zones where good agricultural practices against soil erosion could be more profitable.

Recent soil surveys led to more detailed maps (1:50.000 scale) of hilly side of Emilia-Romagna and a new project started in 2013. The LIFE HELPSOIL project - *Improving soils quality and strengthening the adaptation to climate change through sustainable techniques of Conservation Agriculture* – will contribute to enhance knowledge on soil erosion through sub-basin modelling and single-slope scale monitoring.

### SOIL EROSION MODEL

The RUSLE (Revised Universal Soil Loss Equation) model is proposed to evaluate the soil erosion risk.

RUSLE model is based on the following equation (Wischmeier and Smith, 1978):

$$A = R * K * LS * C * P$$

where:

A = Soil Loss ( $Mg \cdot ha^{-1} \cdot y^{-1}$ )

R = Rain Erosivity

K = Soil Erodibility

LS = Slope Length (Morphology) Factor

This model has been calibrated at regional scale and then applied to a river basin, located in the eastern province of Forlì-Cesena. The river stream is Brasina creek, tributary of Montone river. The Brasina basin has a total area of 3.408 hectares, divided between 3 municipalities (Predappio, Dovadola and Castrocaro), with altitude ranging between 50 and 700 m a.s.l. and annual rain of 800-1500 mm. The geological base of the Brasina basin is known as "Marnoso-arenacea" formation, which is the parent material of soils very variable in texture, ranging from fine to coarse loamy texture family. In these soils the erosion may result either in laminar flow or in moderate rills' occurrence or in weak soil slipping, as a consequence of slope variability.



Figure 1 – Rills evidence on slopes ranging from 10 to 35%, despite temporary cross ditches. Soil cover by winter wheat.

Topsoil erosion risk is highly dependent on land use and agricultural practices. The regional land use map (2008) assigns to protective classes (forest and meadows) 42% of total area, whilst 44% (arable and horticultural crops) is considered to be less effective in reducing the erosion risk. For these land use classes the vulnerability to erosion depends mainly on management practices: soil cover rate during rainy seasons, intercropping or grass cover for permanent crops.



Simulations by means of the RUSLE model identified some 32% of total basin area affected by erosion risk at high rate ( $>50 \text{ Mg} \cdot \text{ha}^{-1} \cdot \text{y}^{-1}$ ) and 8% at a moderate level ( $20\text{-}50 \text{ Mg} \cdot \text{ha}^{-1} \cdot \text{y}^{-1}$ ).

### CONSERVATION AGRICULTURE FOR SOIL EROSION MITIGATION

In Emilia-Romagna agricultural soils in hilly areas ( $100 < \text{altitude} < 600 \text{ m a.s.l.}$ ) are devoted to very contrasting farming systems: arable crops rotation, orchards and vineyards on permanent grass cover, livestock farming based on cereals-alfalfa cropping systems. These two latter can obtain a high level protection of topsoil against rain erosion, whilst arable rotations can result in huge soil losses ( $> 20 \text{ Mg} \cdot \text{ha}^{-1} \cdot \text{y}^{-1}$ ).

Agricultural soils on slopes above 10% must be managed with conservation practices as temporary cross ditches to reduce slope length (Good Agricultural and Environmental Conditions, as provided for by Reg (CE) n. 73/2009).

Conservation Agriculture is a production system based on a combination between minimum or no tillage and a continuous soil cover, obtained by crops or crop residues.

Conservation agriculture's techniques are well known and widespread on plain areas in several countries. Their positive effects as referred to SOM conservation and compaction prevention, jointly with an higher rain infiltration rate, should result in soil erosion mitigation on sloping land, as well.

The project LIFE HELPSOIL (LIFE12 ENV/IT/578) will demonstrate the feasibility of conservation agriculture, in association with some novel techniques, in order to achieve best soil management. Its activities are running in 20 pilot farms in the river Po plain (northern Italy); 4 pilot farms are located in Emilia-Romagna.

"Gli Ulivi" farm, with a total area of 300 hectares, has a cereals, livestock feed and vineyards cropping system. It is a part of the basin of Brasina creek, where RUSLE erosion model, as above described, has been testing. This farm has long, wavy 10-40% slopes with predominant East orientation and altitude ranging from 295 to 420 m a.s.l. Soils were formed on a pelithic-arenaceous rock-bed, with parent material at 90-100 cm depth. These soils are medium-textured, calcareous, with frequent Ca-carbonates concentrations, from moderately deep to deep.

An arable plot at "Gli Ulivi" farm, situated on a slope with high potential erosion risk, is managed to compare conservation and conventional agricultural techniques.

During 2014-2015 winter season the monitoring of contrasting management effects started, to be continued over two years following. Monitoring is based on visual methodology, according to Visual Soil Assessment (FAO, 2008). Results will be also validated with modelling to test site significance as a part of the river basin.



Figure 2 – Conservation agriculture treatment on 20% slope: no till winter wheat, 60% soil cover, no soil erosion occurring (24.02.2015).



Figure 3 – conventional agriculture treatment on 20% slope: tilled winter wheat, 40% soil cover, low sheet soil erosion occurring (24.02.2015).

### ACKNOWLEDGEMENTS

We are grateful to the colleagues of Regional Soil Service for their contribution.

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## ELEVATED GEOGENIC CONTENTS – EXEMPLIFIED FOR ARSENIC IN SOILS OF BAVARIA

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**KEY WORDS:** soil contamination, elevated geogenic contents, arsenic, German Soil Protection Act.

### Introduction

In Bavaria there are regions with elevated geogenic contents of metals and heavy metals (Bayerisches Landesamt für Umwelt 2011). For example, the rocks of the old basement in East Bavaria have high contents of chromium and nickel. Near the city of Weiden there are large sources of lead in soils. A common feature in Southern Bavaria are high arsenic contents in soils. These become problematic when soil is excavated in construction measures. For instance, problems to dispose excavated soil material occurred when the 3<sup>rd</sup> runway of Munich Airport was built. Values up to 2000 ppm were measured. Furthermore elevated contents were encountered in the soil material when upgrading highway A8 near the small town Burgau etc. In Germany the threshold value for harmless arsenic concentrations is 20 ppm. § 12 of the Federal Soil protection Ordinance is regulating the handling of soil material which exceeds the threshold value (BBodSchV 1999). The important principle of § 12 is the prohibition of soil degradation. It is not allowed to put higher contaminated on less contaminated soil. The Bavarian Environment Agency published a leaflet which explains how to deal with arsenic contaminated soil material (LfU, 2014). For application of the requirements it is important to know the distribution of arsenic-contaminated soils in Bavaria. Hence the Bavarian Environment Agency started a project on vertical and horizontal arsenic distribution in soils of Bavaria (2013-2016).

### Procedure and Methods

The project was structured in the following steps:

- All archived data were compiled, which comprise data from approximately 1500 soil profiles
- To get sufficient data for creating soil maps by taking into account soil substrates and geostatistics (ordinary kriging) ca. 1000 locations are going to be sampled additionally (fig. 1).

- Using driving core drillers samples will be taken down to 1 m soil depth.
- For getting information on the deeper subsurface approximately 100 further locations will be sampled down to a depth of minimum 5 m. This is the average depth for a soil excavation when building a single family house.

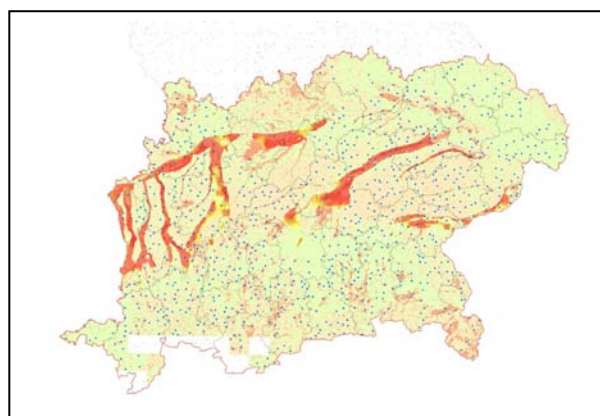


Figure 1 –Sampling points and areas with tertiary groundwater (red colour).

Following analysis methods were applied:

- Elementary analysis (Carbon, nitrogen and sulphur),
- pH-value (CaCl<sub>2</sub>),
- Aqua regia extract,
- S4-water extract (solid-liquid ratio 1:10).

The analysis is requested in the Federal Soil Protection Ordinance. These methods are chosen to better characterize the features of arsenic: 1) Arsenic has a high affinity to humus. 2) Increasing acidification is causing a higher solubility of arsenic.

### Results

The investigations we made to date give the following interesting hints:

- Arsenic is found predominantly in tertiary sediments or nearby rivers where tertiary groundwater is reaching the surface (Fig. 1).
- Arsenic is particularly fixed at ferric (hydro-)oxides and organic substances. If there are brown or very dark colours on the low-land and valley fields the probability is high that arsenic contents are elevated.

- High contents are found in peatlands, which can be traced back to tertiary groundwater that is responsible for the accumulation of arsenic in humus.
- If there is a reductive situation in the soil, arsenic can be dissolved. This could be dangerous for plants (LABO 2013). Besides the mobile arsenic could reach the groundwater and be hazardous for human health.

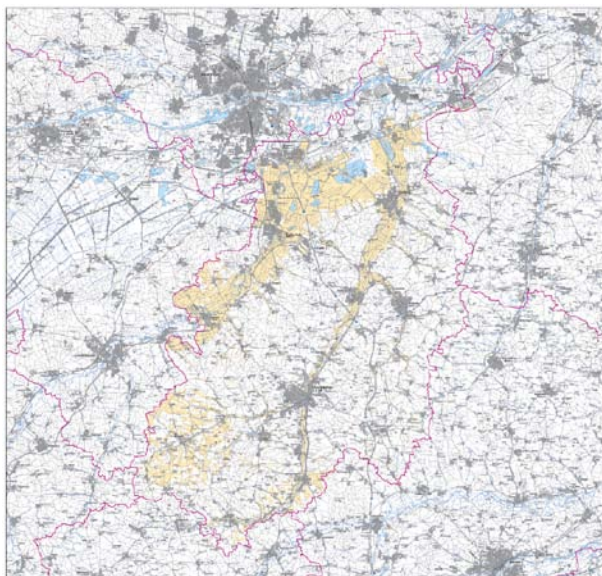


Figure 2 – District map with arsenic distribution.

### Discussion and conclusions

The leaflet of the Bavarian Environment Agency (LfU, 2014) shows how to deal with elevated geogenic contents of arsenic. Especially it offers support what to do with contaminated, excavated soil material. The main target of the leaflet should be waste prevention. If there is no chance to avoid soil excavation and the soil material has to be transported to other locations other options of operation have to be chosen. Maps of the arsenic distribution in soils (Fig. 2) can be used as a base of decision support. If a construction project is planned in an area with elevated geogenic arsenic contents:

- special sampling and analysing could be ordered by the authority. Those results should serve as a decision-making tool whether the waste soil material is suited for landfill, filling of holes and pits, or has to be used either for technical buildings or deposited in waste dumps,
- an alternative area for implementation of the construction project could be looked for,
- “waste material to waste material”. This principle means if you have contaminated excavated soil material you can transport it to another area in the district with similarly elevated contents.

Hence, it is extremely helpful for Bavarian authorities to utilize the leaflet and the district maps for applying the requirements of the Federal Soil Protection Act (BBodSchG 1988) and its Ordinance.

### ACKNOWLEDGEMENTS

We are grateful to the Bavarian Ministry of the Environment and Consumer Protection for financing the project. Sincere thanks are given to the “Engineers for Soil Protection” of the water management authorities who take many samples of the investigation area. Besides we want to thank our laboratory in Marktredwitz for analysing the soil samples.

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## TOOLS TO FACILITATE THE USE OF SOIL MAPS IN EMILIA-ROMAGNA REGION (ITALY)

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**KEY WORDS:** soil map, delineation, soil typological unit, benchmark local site, websites, fertilization plan.

### INTRODUCTION

Soil maps are not easy to manage. Very often legends are based on soil classifications (e.g. Soil Taxonomy, W.R.B, local classifications) understandable by a limited number of users (mostly soil scientists).

Their readability can be improved by “translating” them into simpler documents more clear and easy use. The thematic maps derive from soil maps and can be, for example, Land Capability maps, suitability maps, permeability maps, other maps that represent single parameters as pH, organic carbon, clay etc.

In Emilia-Romagna region the last printed soil map, such as the Soil Map at 1:250.000 scale, has been published in 1994. Since then every soil and thematic map have been published via the Internet on cartographic websites. This method has many advantages since allows:

- Frequent update;
- Ability to add much more information that would not be possible to provide in a printed map;
- Free downloading (no need for users to asking data to producers or buying printed maps).

The first cartographic website on regional soils, originally called “Soil Inventory of Emilia-Romagna plain”, is online since 1998.

Over the years, the Web sites on soils have become three, based on different technologies and directed to different users.

However, these websites are based on the same geodatabase and share the same approach of data usage:

- use of polygons (delineations) of the 50k soil map as individual objects;
- soils present within a the delineation are described on the basis of their localization, percentage presence, any differences from the typical range of properties of the regional soil typological unit;
- every soil, identified by a code and a name, is linked to a benchmark local site summarizing the main chemical and physical characters;

- use of a identification tool (wizard) of soils inside a single delineation on the basis of a series of questions and answers (1 to 6 steps);
- use of extension service soil analyses (about 40.000) to identify soils and to input soil data necessary for the calculation of fertilization plans.



Figure 1 – Websites on Emilia-Romagna soils

### SOIL DELINEATIONS OF THE 50K SOIL MAP

The Soil Map at 1:50.000 scale (2014 edition) covers the whole plain, 82% of the hills and a small part of the mountains. N. 6294 soil polygons are delineated in this map.

Each polygon (delineation) of the soil map is identified by a numerical ID and has a specific and unique soil component (soil type, % presence, localization).

The description of each polygon allows to provide specific information about local soils. This is not possible using a Mapping Unit description. Within a soil polygon the number of soil types (Soil Typological Units or STU) ranges from 1 to 12 (on average 3-4).

At present 389 STU have been described at this scale. Some of these soils are widespread and cover thousands of hectares; others are rare and present in specific landscapes only.

ID (della)	Tipo	Data Agg.	Grado Fiducia modello distribuzione suoli	Metodo apposizione Limite	Fiducia Limite
7195	risulta e descritta singolarmente	09/12/2008	Buono	Controllo diretto in campo con distribuzione delle osservazioni itine	alto
Unità cartografica					
Lotto UC	Cod UC	Sigla UC	Descrizione UC		
A8005	E145	CTD1	consociazione dei suoli CITTIDELLA Franco Imosi. 1-0% pendici		
Note sui suoli					
Il CITTIDELLA non presentano incremento di argilla in profondità					
Ambiente					
Geomorfologia		Caratteri Stazionali		Uso del Suolo	
terran su terrazzi con superficie ondulata				terreni su ondulati, prati ondulati, vigneti	
Distribuzione dei suoli nella delineazione					
Suoli presenti			Distribuzione		
Archivio	Suolo	Nome Suolo	Rappresentatività regionale	% Fiducia	Localizzazione
F5008	CITD1	CITTIDELLA Franco Imosi. 1-0% pendici	Osservazioni comate	75	distribuzione omogenea
F5008	RUC1	RIVERGARO Franco Imosi	Osservazioni rappresentative	25	parti alte delle incisioni, parte tipica della paleoconode
			Siti di riferimento nella delineazione		Localizzazione
			515		rappresentativo nella delineazione
			521		comate nella delineazione

Figure 2 – Example of a delineation form.

## BENCHMARK LOCAL SITES

Every soil in every delineation has been linked to an analyzed site that has been surveyed in the same polygon or in adjacent polygons. The choice of these sites (benchmark sites) accounts for the local variability.

For this purpose have been selected from the Soil Information System 2875 observation sites (profiles and auger holes) that have, at least up to a depth of 100 cm, these analytical and calculated data:

- sand, silt and clay;
- pH;
- organic carbon;
- total calcium carbonate;
- bulk density;
- Ksat.

In a typical site, from the surface to a medium depth of 145 cm, are available on average 4 samples. The depth ranges from 30 cm (skeletal soils or soils with lithic or paralithic contact within 100 cm) to 500 cm (strongly weathered soils).

Benchmark sites can be used for many applications, such as:

- Soil Type Identification;
- Input data for irrigation projects;
- Input data for Water Balance Models (e.g. MACRO, PELMO);
- Input data for fertilization models;
- Input data for Risk Assessment Models for contaminated sites (e.g. ASTM E2081);
- Building of derived maps as e.g. Land Capability Map or Permeability Map.

## TOOL FOR IDENTIFYING DIFFERENT TYPES OF SOIL (WIZARD)

This tool works by following a dichotomous path: the users must choose between different options until a single result. To building this tool 88 groups of soils have been defined and each delineation, according to its mapping unit, has been allocated to a group of soils.

A number of soils (2 to 27) has been assigned to a each group, on the basis of the mutual presence of soils in the landscape.

19 parameters, displayed as questions, can be used to make the choices. Each parameter corresponds to a set of values (2 to 32) and each value corresponds to an answer.

For each group 1 to 6 parameters have been assigned to differentiate soils.

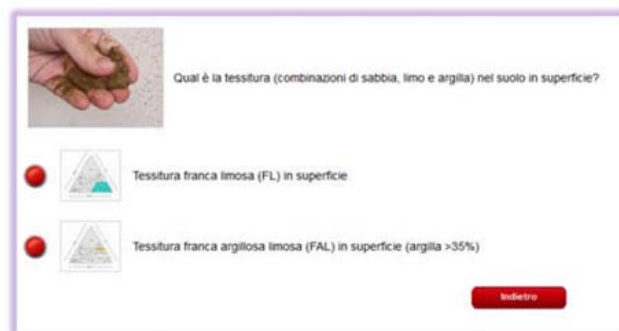


Figure 3 – Choice between 2 topsoil texture classes

## USE OF EXTENSION SERVICE SOIL ANALYSIS

These data are routine chemical-physical analysis (sand, silt, clay, pH, total carbonate, active carbonate, organic matter, available K, available P, total N) of about 40,000 soil samples (mostly on superficial horizons). They can be used in two ways:

- Identification of a type of soil;
- input soil data necessary for the calculation of fertilization plans.

Most of these data, represented as a point layer, are linked to a STU. The user can check if there are extension service soil analysis inside or nearby the area of interest.

Moreover in the website “Soil Inventory of Emilia-Romagna” it’s possible to calculate a fertilization plan. The user can use its own soil analytical data or take advantage of the already available soil data. After choosing the type of soil, the user can use the medium values inside the delineation of these analytical data as input data for the calculation.

## ACKNOWLEDGEMENTS

We are grateful to Marica Landini, Giulio Ercolessi and Francesco Marucci for their great job as website builders.

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## SOIL MAPPING IN THE BAVARIAN ALPS – AN EXPERIENCE REPORT

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**KEY WORDS:** *soil mapping, Bavaria, Alps*

### INTRODUCTION

Soil mapping in the Bavarian Alps started in the late 1990ies. It was the last region of Bavaria under examination in the course of developing an outline soil map at the scale of 1: 25000. It is called "Übersichtsbodenkarte 1:25 000" (ÜBK 25) and this map series with a drafting character will be finished in 2015.

The mapping concept has to meet the following requirements:

- Smooth integration of the alpine mapping units into the existing General Legend of Bavaria.
- Mapping must be possible even in the case of fragmentary or missing data (e.g. geological map).
- A tight time schedule must be adhered to.

### THE CONCEPT

It was clear from the beginning that a stratigraphic structure of the mapping units as in other Bavarian landscapes is non-applicable.

As a consequence the modification of previously used conceptions with the aim of correct representation of the alpine landscape must be installed.

Anyway, as in other regions of Bavaria three fundamental particulars must be content of every mapping unit: soil type(s) inclusive spatial ratio, texture and parent material. This is the basis for further applications.

Due to the strong morphodynamic and morphologic interaction these facts have to be considered. Thus, mapping units composed of a

connection between soil type and lithologic or rather morphologic/morphodynamic structured parent material were established. Therefore, a morphologic or morphodynamic term can be substituted for parent material.



*Figure 1 – Common business in the Alps – Cambisol (Moraine with crystalline debris, left) and Regosol (Moraine with carbonatic debris, right)*

### PROBLEMS AND SPECIAL FEATURES OF THE ALPINE AREA

Moving in the Alps of course implies logistical problems like limited traffic ability and accessibility. You also have to take into account that topography causes a multiple area to map.

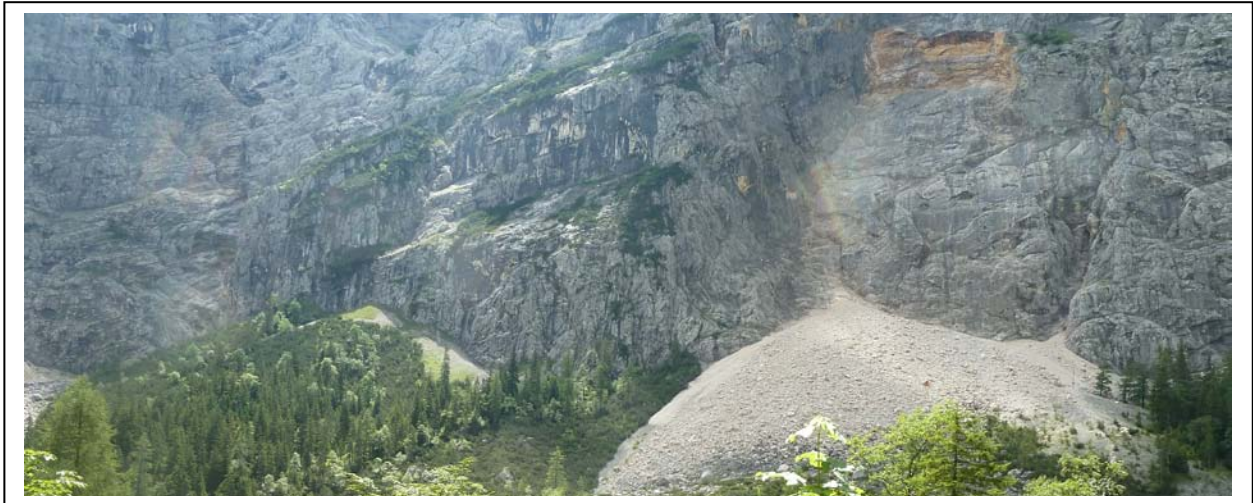


Figure 2 - Example for distinct soil development caused by recent morphodynamics

Missing or inadequate representation of the intense quaternary and Holocene coverage or overprint on geological maps is a prominent phenomenon caused by the different intentions.

Soil estimation maps provide useful information for soil mapping in other regions in Bavaria. In the Alps however, they are nearly meaningless.

Tectonics, relief intensity and both former and recent morphodynamics induce a small-scale changing of soil type and substrate conditions (Fig. 1, 2). Thus, it is difficult to define legend units.



Figure 3 – Organic rich debris below residual stone pavement (periglacial zone, altitude 2500m)

## CONCLUSIONS

A very important approach to overcome those specific problems is to create hierarchical systems, enabling the use of the fittest level reflecting the reality at its best. This means the mapping unit as well as the classification of the soil.

But even using a hierarchical classification system like the German one (Ad-hoc-AG Boden, 2005), some of the soils cannot be described correctly (Fig. 3). Regarding the small Alpine area of Germany it is understandable that the classification system is not devoted to alpine soils. This implies also a lack of knowledge about interactions of soil forming factors and soil forming processes especially at higher altitudes.

Therefore, upgrading knowledge of alpine soils and classification systems is a necessary task for now.

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## GEOCHEMICAL MAPPING AND ENVIRONMENTAL RISK ASSESMENT OF CONTAMINATED SOILS ASSOCIATED WITH MINING ACTIVITY: EL CAMPILLO, (HUELVA PROVINCE, SPAIN).

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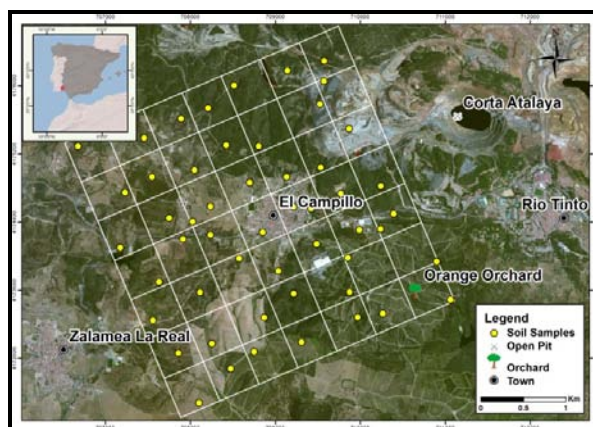
**KEY WORDS:** Mining, contaminated soils, geochemical mapping, lead isotopes

### INTRODUCTION

Soils are affected by dispersion of pollutants as a result of their close relationship with the atmosphere and with surface and groundwater. The distribution and type of contamination depend closely on climate, rain, drainage, vegetation, lithology and human activities. It is well known that soil contamination due to heavy metals and metalloids represents the source of a severe potential hazard for ecosystem equilibrium and health of living beings.

Geochemical mapping with Geographic Information Systems (GIS) and lead isotopes analysis are techniques that can be used for mapping and monitoring the extent of soil contamination. The results can aid in distinguishing natural versus anthropic activities. These techniques can be fundamental tools for informed management of land use, and for implementation of environmental regulations aimed at protecting the health of biological systems and proper development of natural resources.

The present work is dedicated to the environmental geochemical mapping and environmental risk evaluation in El Campillo, Spain; the area is located in the Rio Tinto mining basin (Figure 1). The aim of the work is to identify the origin, dispersion mechanisms and distribution of pollutants possibly associated with a long history of mining. Also, an effort is being made to monitor the influx of contaminants into the human population (analysis of human hair using Pb isotope techniques).



**Figure 1 - Map shows the study area and sampling points.**

### CASE STUDY

This study is carried out in El Campillo, part of the Rio Tinto mining basin, located in the Iberian Pyrite Belt (IPB), which is characterized by abundant polymetallic sulfides that have been exploited for over 5000 years. The IPB is located in the south-western domain of the Iberian Massif, composed of slate and turbidites of Paleozoic age (Middle Devonian-Carboniferous) deposited in a deep marine environment. A volcanic system in the basin resulted in an important metal volcano-sedimentary deposit of massive sulphide (e.g. Romero et al, 2010; Marcoux, 1998)

The regional climate is Mediterranean, but is influenced by the presence of the Atlantic Ocean. Insolation is high and the region is classified as semiarid with low precipitation (700 mm/year), low vegetation cover, and poor soil development (Font Tullot, 1983)



## ANALYTICAL METHODS AND FIRST RESULTS

For the purpose of this work, 50 top soil samples were collected during the spring of 2014. Each sample was collected according to a regularly spaced sampling grid (500x500 m). The samples were prepared and sent to a certificate laboratory for ICP-MS analysis. Statistical and geostatistical analyses were performed on the analytical results, in order to get the baselines and the geochemical mapping of the elements spatial distribution. This research focused on the following elements as harmful to living beings: arsenic (As), cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), selenium (Se), zinc (Zn), Tin (Sn), vanadium (V), beryl (Be), molybdenum (Mo), bismuth (Bi). Hair samples were also collected from local people, to be analyzed by ICP-MS and to help understanding of the origin of harmful elements near El Campillo. The lead isotope signature of soils and hair samples is under analysis to determine if the presence of toxic elements is associated with mining activity or if there are other anthropic sources in the area that could further enhance a negative impact on the environment.

The geochemical mapping (Figure 2) shows that the toxic elements are concentrated around the mining tales. Also, our data evidence the presence of high concentration of contaminants in urban areas and agricultural soils, suggesting the presence of different contamination sources or the influence of the mine.

The final aim of this work is to contribute to a better understanding of the dispersion of contaminants from the source to the food chain. In El Campillo, agriculture has been established around the mining area, and our study is the first effort to examine the relationships between contaminants dispersed from the mine and their diffusion through the food chain, up to human beings.

## ACKNOWLEDGEMENTS:

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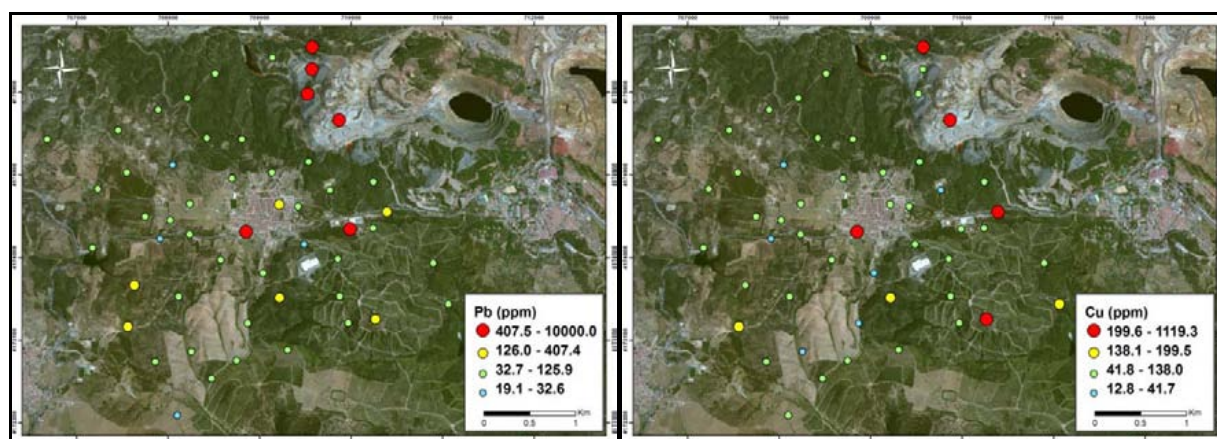


Figure 2 - Geochemical point map, with Pb and Cu distribution.

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## **SOILS: FUNCTIONS AND THREATS - POSTERS**

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## THE SOIL MAP OF THE INSTITUT CARTOGRÀFIC I GEOLÒGIC DE CATALUNYA

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**KEY WORDS:** soil, soil mapping, soil mapping programme, soil information, geoworks of Catalonia, geomaps of Catalonia.

### INTRODUCTION

The "Institut Cartogràfic i Geològic de Catalunya" (ICGC) was created on January 2014. Their duties are related to the competences of geodesy and cartography and about the spatial data infrastructure of Catalonia, and also to the competences of promoting and carrying out the actions related to the awareness, survey and information about the soil and subsoil.

In order to perform this task, the ICGC has to execute, in collaboration with other organizations and/or private companies when needed, different works related to soil mapping, land evaluation and land protection.

It is in this context that the ICGC has decided to continue the soil mapping programme, established on June 2009 by the former Geological Institute of Catalonia (IGC), as the best strategy to generate, store, process and spread the soils information of Catalonia.

One of the main aims of this project is the publication of the soil map (1:25.000) of Catalonia.

### CHARACTERISTICS OF THE SOIL MAP

The soil map of the ICGC is going to be distributed according to the 304 sheets of the topographical map of Catalonia (Figure 1).

The map is basically intended for technicians with some experience in the handling and reading of soil maps and, with certain limitations, to other unskilled users.

Information is structured around the map to allow different reading levels, from the most basic, in which the user identifies the type of soil at a specific spot in the area (two dimensions), the deduction of what may appear at a particular point through the sequence of horizons (three dimensions) to the interpretation of the suitability

of soils for different scenarios that may arise (soil evaluation, four dimensions).

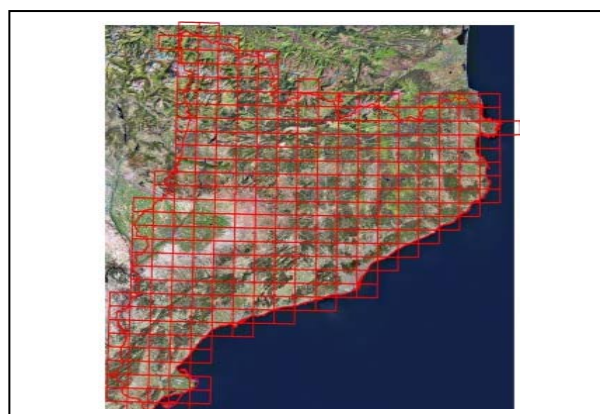


Figure 1 – Scheme of functionality.

Each sheet is basically formed by the soil map, a set of graphic elements (photos, schemes and tables) and some text that allows understanding the soil characteristics of the territory represented (Figure 2). They are, therefore, self-consistent documents that contain all information necessary for a proper interpretation.

The (1:25.000) soil map is the central element of the sheet and contains all delineations that provide essential information about the main soils types that appear in the area and their spatial distribution. The basic map units are consociations of these main soil types, although complexes are also allowed if it is justified by the soil distribution pattern.

The legend consists of an organized list of the map units that appear on the map. In this case, map units contain the name of the main soil types and their classification according to the Soil Taxonomy system (SSS, 1999) and the Word Reference Base for soil resources (IUSS, 2007).

Soil types have been defined based on the parent material, effective soil depth, drainage class, presence and distribution of diagnostic horizons, texture, presence and composition of rock fragments, concentrations,

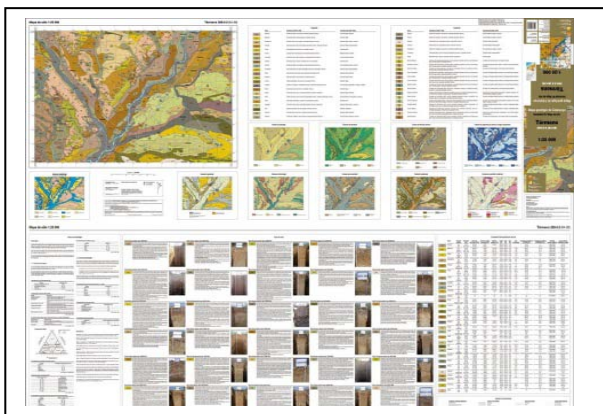


Figure 2 – Sheet 64-28 (Térmens) of the soil map (1:25.000) of Catalonia.

For ease of use, map units have been sorted, simply, alphabetically. Furthermore, it must be noteworthy that, in order to lighten the map legend, it does not explicitly list the phases of the map units, although they are included in the associated soil information system.

Complementary maps and schemes are included in the soil map sheets; they are intended to facilitate the interpretation and visualization of important soil characteristics: soil depth, drainage class, underlying material, available water holding capacity and the agrological capacity classes of the soils.

The description of the main soil types provides essential information on their spatial distribution in the territory and their morphological characteristics: soil depth, presence and distribution of different horizons, color, texture, coarse fragments, structure, consistence, soil penetrability, concentrations, cutans, human activity, biological activity...

In addition, in order to get a better understanding of the different soil types that appear in each sheet, all descriptions are accompanied by a picture that tries to illustrate the main characteristics of their morphologies.

A table, summarizing some of the most important chemical (soil reaction, electrical conductivity, organic matter content, calcium carbonate content, cation exchange capacity) and physical (texture, bulk density) characteristics also complements soils descriptions.

Published sheets contain a methodological summary that explains, briefly, how the map has been executed and the technical criteria that have been used in the identification and description of the different soil types and soil map units that shape the soil map. A more detailed document, with the technical specifications required for the

implementation of the ICGC soil mapping programme, can be found on the ICGC website ([www.icgc.cat](http://www.icgc.cat)).

All information collected and generated during the execution of the mapping projects is stored in the corresponding databases and integrated into the soil information system of the ICGC. In this way, storage, edit, processing, analysis, recovery and presentation of the information are enormously facilitated.

The soil catalogue is one of the main products of the soil information system. The creation and maintaining of this catalogue allows soil scientists that participate in the soil mapping programme of the ICGC to access the official and updated collection of the soil types that are applicable to their soil survey areas.

The major items in description of the soil types of the catalogue are: general description, background, distribution and extend, range in characteristics, remarks on diagnostic horizons and features recognized in the pedon, land use, typical pedon and date of latest revision.

The soil map (1:25.000) of Catalonia is available on the website of the ICGC. Individual sheets can be downloaded, in raster format, as soon as the individual maps are published. In the near future, it is intended that all cartographical information is also going to be distributed in vector formats.

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## ANALYSIS OF PYRETHROID AND ORGANOCHLORINE INSECTICIDES IN SOIL.

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**KEY WORDS:** soil, pyrethroids, GC-MS, UAE.

### INTRODUCTION

The use of pyrethroids as insecticides has increased in recent years as a substitute for organophosphates, which had already replaced organochlorine compounds, due to their relatively lower mammalian toxicity and lower environmental persistence. However, pyrethroids may have a negative impact on the environment, primarily on water bodies, due to their toxicity to arthropods and fish (Solomon et al., 2001; Weston et al., 2005) and their bioaccumulation potential (Corcellas et al., 2015). Additionally, DDT, a pesticide banned in Europe and other countries, is often found in the environment together with its metabolites because of their high persistence and accumulation (Quesada et al., 2014).

Pesticides may enter to the environment through deposition, runoff or leaching after their application in agricultural fields (Wang et al., 2012; Weston et al., 2013). Pesticides persist longer linked to organic matter and clay, and may reach the aquatic compartment, where they represent the worst case scenario.

Thus, the aim of this work was to develop an easy, robust and environmental friendly method (low volume of organic solvent and amount of sample) to assess the occurrence of pyrethroids and organochlorine pesticides in soil samples.

### MATERIALS AND METHODS

Insecticides 4,4'-DDE, 2,4'-DDT and 4,4'-DDT, (100 µg/mL in nonane purity higher than 98%) were supplied by Supelco (Bellefonte, USA), resmethrin (RESM), bifenthrin (BIFE), fenprothrin (FENP), λ-cyhalothrin (CYHA), permethrin (PERM), cyfluthrin-I (CYFL), α-cypermethrin (CYPE), τ-fluvalinate (FLUV), esfenvalerate (ESFE) and deltamethrin (DELT) (100 µg/mL in nonane purity 99%) were supplied by Riedel-de Haën (Seelze, Germany), whereas internal standard 4,4'-DDD and trans-permethrin-D6 (100 µg/mL in nonane purity >99%) used as surrogate standard were supplied by Supelco (Bellefonte, USA) and Symta (Madrid, Spain), respectively

Extraction and clean-up of pyrethroids, DDT and its metabolites from soil was carried out by ultrasound assisted extraction (UAE) Briefly, 1 g of sieved soil was placed in a glass column

containing 1 g sodium sulfate and 1.5 g of Florisil over a paper filter and frit.

For the recovery studies, samples were previously fortified with a mixture of the different analytes to reach final concentrations of 10 ng/g and 2 ng/g and the labeled internal standards at 10 ng/g and they were kept at room temperature during 24 h to allow solvent evaporation. Soil samples were extracted twice for 15 min in an ultrasonic water bath with 2 x 5 mL ethyl acetate and washed with an additional 1 mL. The combined extracts were collected in 10 mL graduated tubes using a multipoint vacuum manifold, concentrated to 0.1 mL using a gentle stream of nitrogen and analyzed by GC-MS.

GC-MS analysis was performed with an Agilent 6890 (Waldbronn, Germany) gas chromatograph HP 7683 and an inert mass spectrometric detector (MSD), Model HP 5973N. A fused silica capillary column ZB-5MS, 5 % phenyl polysiloxane as nonpolar stationary phase (30 m x 0.25 mm i.d. and 0.25 µm film thickness), from Phenomenex (Torrance, CA), was used for the analysis.

Operating conditions were as follows: 5 µL of soil extract were injected in solvent-vent mode. The temperature program started at 50 °C, kept for 0.1 min, then ramped to 300 °C at 600 °C/min, held 5 min, and finally decreased to the initial temperature cooling with compressed air. The column temperature was maintained at 50 °C for 2.6 min, then programmed at 20 °C/min to 300 °C and held for 5 min. The total analysis time was 20.1 min and the equilibration time was 4 min.

### RESULTS AND DISCUSION

In order to evaluate the method developed for the detection of insecticides in soil, different quality parameters were studied: recoveries, reproducibility, linearity and sensitivity.

The recoveries obtained spiking soil at two concentration levels (10 and 2 ng/g) were satisfactory to all the compounds, ranging from 75 to 107% (Table 1). The precision of the analytical procedure was determined by the relative standard deviations (RSD, %) of the replicates (n=4) and ranged between 1 and 11%.

Limits of detection (LODs) and quantification (LOQs) are ranged from 0.1 to 0.4 ng/g and 0.3 to 1.2 ng/g, respectively allowing to detect in soil insecticides at trace levels, Table 1.

Name	Fortification levels		LOD (ng/g)	LOQ (ng/g)
	10 (ng/g)	2 (ng/g) <sup>a</sup>		
	Mean ± RSD	Mean ± RSD		
2.4'-DDE	108 ± 6	79 ± 10	0.3	0.9
2.4'-DDT	77 ± 4	114 ± 3	0.2	0.5
4.4'-DDT	108 ± 7	77 ± 3	0.1	0.4
RESM	104 ± 4	75 ± 1	0.4	1.2
BIFE	103 ± 2	100 ± 9	0.1	0.3
FENP	107 ± 3	107 ± 3	0.2	0.7
CYHA	95 ± 9	96 ± 9	0.1	0.4
PERM	94 ± 5	98 ± 11	0.1	0.5
CYFL	97 ± 4	102 ± 4	0.3	1.1
CYPE	96 ± 7	97 ± 10	0.2	0.8
FLUV	92 ± 8	108 ± 4	0.3	1
ESFE	101 ± 8	106 ± 7	0.3	1
DELT	99 ± 7	75 ± 2	0.3	0.9

Table.1 - Recoveries (%) (n=8) with their relative standard deviation (RSD). Limit of detection (LOD. ng/g) and limit of quantification (LOQ. ng/g) of the studied insecticides (n=10).

A multipoint calibration curve with five standard solutions at different concentration levels (from 1 to 100 ng/g), appropriate to the levels found in soil samples, was used. The surrogate standards were added at the concentration of 10 ng/g for all levels. A good linearity of the calibration curves was obtained in the studied range with  $R > 0.999$  for all compounds.

Once the method was optimized and validated it was used in real samples as shown in Table 2.

Name	Soil			
	1	2	3	4
2,4'-DDT	1.3±0.2	1.7±0.2	0.4±0.1	1.1±0.1
4,4'-DDT	nq	nq	nd	nq
4,4'-DDE	1.3±0.2	0.7±0.1	0.4±0.1	1.0±0.1
RESM	45.7±1.5	71.6±1.2	70.1±3.7	45.9±2.5
CYFL	14.1±2.6	6.9±0.7	1.5±0.3	3.7±0.4
CYPE	3.9±0.5	1.2±0.1	4.6±0.3	1.1±0.1
ESFE	29.7±1.4	10.4±2.7	1.6±0.1	1.2±0.1

nd, not detected; nq, not quantified

Table.2 - Concentration of the studied compounds (ng/g) found in agricultural soil collected from fields in Castilla-Leon (Spain).

Pyrethroids and organochlorine insecticides were found in soil. DDT and its metabolites appeared in samples but at relatively low levels (up to 1.7 ng/g). Whereas pyrethroids were detected at higher concentration, being four out of ten of them detected at levels from 1.1 to 71.6 ng/g.

A representative chromatogram of soil sample containing cyfluthrin-I at 14.1 ng/g is depicted in Fig. 1.

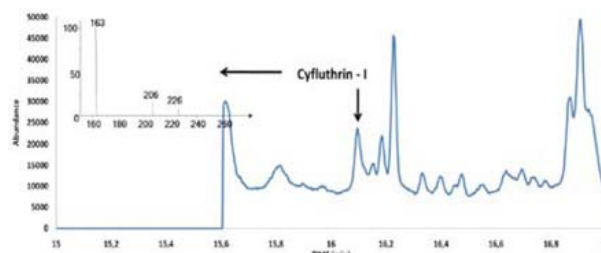


Figure.1 - Partial view of a chromatogram of a soil extract where cyfluthrin was detected.

## CONCLUSIONS

A multiresidue method for the determination in soil of 13 insecticides (pyrethroids and organochlorines), based on UAE method, has been developed and validated with satisfactory recoveries. GC-MS was used for its high selectivity allowing the identification and quantification of the studied contaminants at low levels. This method was applied in 4 agricultural soils and the presence of some of the studied contaminants was confirmed, being pyrethroids the compounds mainly detected at higher concentrations.

## ACKNOWLEDGEMENTS

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## REMOTE SENSING IN THE STUDY OF THE CONTAMINATED AREAS

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**KEY WORDS:** remote sensing, RapidEye, mining areas, heavy metals.

### INTRODUCTION

The study area is mining area of Niccioleta–Val d’Aspra located about 6 km NE of town of Massa Marittima, near Grosseto, South Tuscany. It is an abandoned mine where pyrite and Pb-Zn (Ag) mineral ores with Fe oxides and hydroxides were mined. The polymetallic mineralizations have been the subject of mining activity, albeit with ups and downs, from the Etruscan period until the mid-twentieth century. Until 1992, the year of closure, mining activity was concerned exclusively to the pyrite mineralizations. This mineral was used for the production of sulfuric acid and iron pellets, in an industrial process which also provided for recovery of heat produced for energy purposes (Lattanzi et al., 1985). In this mine site there are four main landfill, in which fine-grained materials prevail from treatment for ore flotation. The maximum development of the mine is about three kilometers in the sense N-S and about 500-600 m in the sense E-O (Tesser, 2012). Currently, the Niccioleta mining area is part of the Parco Nazionale delle Colline Metallifere Grossetane–Tuscan Mining Geopark, and it is the subject of reclamation with permanent safety (the process is still active).

This study has objective to identify, by means of remote sensing techniques, the presence of minerals that determine the dispersion of toxic elements such as heavy metals.

The work intends to characterize in an alternative and effective these polluted areas, supporting the characterization and remediation of contaminated mining sites, with an approach that increases the efficiency of the process of restoration of the site, saving valuable time and resources.

### MATERIALS AND METHODS

The images used for the study of the Niccioleta mining area, are those of the sensor RapidEy, of 10 June 2012. RapidEy is a constellation of five

heliosynchronous satellites aligned on the same orbit and perfectly identical that allow the acquisition of images at a resolution of 5 meter and 5 multispectral bands of large areas, with a time of revisiting very short (even daily). The bands used in this work are those of the visible, the near and mid-infrared spectral ranges, that are used, in geological and mineralogical studies. This spectral range of VNIR, 0,440-0,850  $\mu\text{m}$  (bands 1-5), allows the identification of minerals in which are present the transition metal, in particular iron. The *RapidEye* images were analyzed by the algorithm *Vegetation Delineation* that, after atmospheric correction, allows to quickly identify the presence and/or absence of vegetation and calculates NDVI. This procedure allows to identify in an immediate the areas without vegetation and concentrate the analysis only in those areas. For the classification algorithm was used SAM *Spectral Angle Mapper* associated with the “Niccioleta Library”, with score of 0.5. The spectral library was built starting from the USGS spectral library Mineral Spectral Library (splib04), it were selected minerals that literature is known for sure, be present in the investigated area. The “Niccioleta Library” was resampled on *RapidEy* data.

### RESULTS AND DISCUSSION

The processed images show that the landfill areas have been subject to reclamation; in fact, they are partially vegetated, despite this fact it was possible to point out, in areas without vegetation, the presence of certain minerals that are formed by the oxidation of pyrite.

The minerals, certainly present in the area, are also those that are more easily detected in the bands of *RapidEye* sensor. Among the transition metals iron is one of the most important since it is present as ferrous ( $\text{Fe}^{2+}$ ) and ferric ion ( $\text{Fe}^{3+}$ ), and this feature allows a good spectral characterization of mafic minerals. Indeed, the presence of iron in minerals and in the rocks is highlighted in the respective spectral signatures from different absorption bands each linked to a specific type of transition. For the ferrous ion ( $\text{Fe}^{2+}$ ) bound to oxygen ions the absorption band is more intense than 1,1  $\mu\text{m}$ , while the ferric ion ( $\text{Fe}^{3+}$ ) has little

intense absorption bands at 0,40, 0,45, 0,49, 0,70 e 0,87  $\mu\text{m}$ . The minerals that contain iron can be distinguished because of these bands absorption. The analysis of *RapidEye* images showed the presence of pyrite and chalcocopyrite followed by

arsenopyrite. The results obtained in these study, point out potentialities of remote sensing applied to the study of these mining areas, indicating the possible advantages of both time and costs, which could be obtained using these techniques.

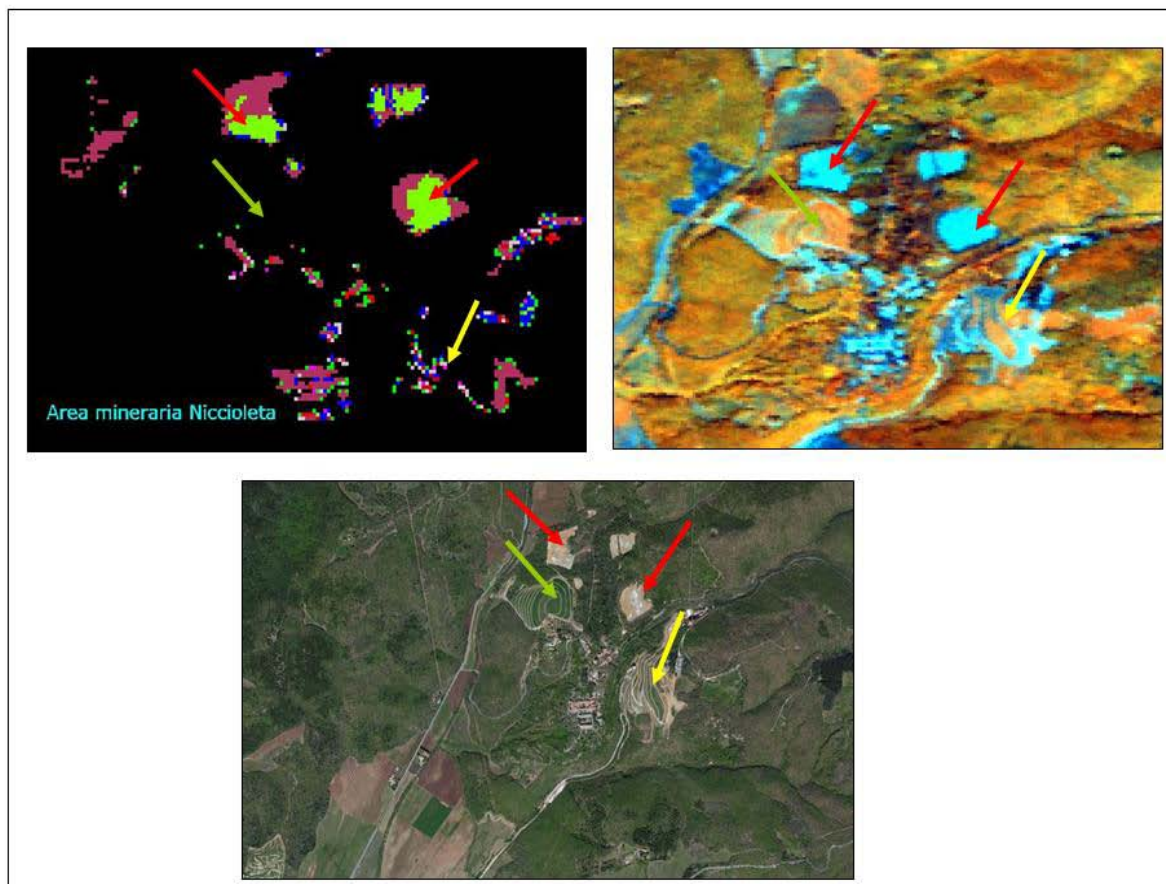


Figure 1 – The Niccioleta mine area, a combination of the image and the orthophoto *RapidEye\_543*. The red arrows indicate areas of the landfill that are under remediation and on these it can still identify the present minerals; the green arrows indicate the areas already cleared, largely covered with vegetation and in this case it is not possible to identify any mineral; the yellow arrows indicate the reclaimed areas but not completely vegetated which are showing some stages.

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## REGIONAL SOIL DISTRIBUTION ON THE WESTERN SIDE OF THE HAȚEG BASIN AND POSSIBLE RELATIONSHIPS OF SOILS WITH PARENT ROCKS

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**KEY WORDS:** soils, classification, parent rocks, Hațeg Basin, Romania.

### INTRODUCTION

Regardless of field of study, the classifications reflect the knowledge of the investigated material. The aim of this paper is to update the nomenclature of soils in the Hațeg area (Romania), as they issued on the map "Soil map of Romania", 1:200.000, *folio* 25-Deva (FLOREA et al, 1990).

The soil classification in Romania is still in progress, so that, a new system of soil classification was coined on 2003, incorporating the advances done in soil research in the time passed since the last classification (1980). The new system, called "Romanian System of Soil Taxonomy" (RSST-2003), is in accordance with the requirements evidenced by the World Reference Base for Soil Resources-2006 (abbreviated, WRB; KRASILNIKOV et al., 2009).

In the RSST-2003, the basic taxonomic unit is the soil type genesis. Is a hierarchical, multi-category system including three higher level categories (class, soil type and subtype genesis) and four lower level categories (soil variety, soil species, soil family and soil variant).

The soil properties are coming from the interaction of multiple factors. The nature of parent material has a high influence on the characteristics of the soil: texture, type of weathering processes, control of natural vegetation composition.

### RESULTS

The studied region is located in the central-western side of Romania. From a geological point of view, it concerns rocks representing either the borders, or the sedimentary filling of the Hațeg Basin occurred in the latest Cretaceous in Southern Carpathians (WILLINGSHOFER et al., 2004). The basin borders concerns metamorphic rocks, while the sedimentary filling refers to conglomerates, sandstones, clays, sandy clays, marls, or rare limestone interbeddings, mostly latest Cretaceous (in dominance Maastrichtian), rather problematic Paleogene-Early Miocene, Middle Miocene (Badenian-Sarmatian) and Quaternary.

Table 1 presents the correlation between soil mapping units of the Soil Map of Romania, scale 1:200,000 (*folio* 25 Deva) and the RSST-2003 system (BLAGA et al. 2005). It has taken into account the correlation of the soil type's genesis of RSST with the main international systems presented by MUNTEANU & FLOREA (2001).

### CHARACTERISTICS OF SOILS IN HAȚEG AREA

The subsoils for **Luvissols-LV** and **Preluvissols-EL** soil type usually contain unconsolidated material, commonly high activity clays that occur in the area here in latest Cretaceous-?Paleogene and ?Lower Miocene deposits. The soils of **Eutricambosol-EC** and **Dystricambosol-DC** type soils naturally form on medium- to fine-textured parent materials, derived from a wide range of rocks. In the studied area, they are located on the borders of the Hațeg Basin, formed on metamorphic rocks. **Rendzinas-RZ** and **Phaeozems-FZ** type soils are less spread, originating on massive, respectively disaggregated calcareous sole, rare in the area. **Podzols-PD** and **Prepodzol-EP** type occupy small areas, generally derived from quartz-rich sands and sandstones or sedimentary debris resulted from magmatic rocks. **Gleysols-GS** and **Stagnosols-SG** are soils saturated by groundwater for long periods and are developed on the unconsolidated material (gravels, sands), mainly Pleistocene-Holocene alluvial sediments. **Aluvisol-AS** type contains soils formed on recent, alluvial (fluvial) deposits and consists mainly of gravels and sands.

### CONCLUSIONS

As mentioned before (VLAD et al, 2012), it is difficult to achieve an accurate description of the soil units on the Soil Map of Romania (1:200.000 scale) using WRB (2006), because many of the soil mapping units have to be redefined using WRB terms, which is almost impossible at this time.

Possible relationships between the soils from Hațeg area issue on their distribution. The largest spread is the ones developed on the main sedimentary fill deposits of the Hațeg Basin, while the ones developed on the basin borders, *i.e.* on older rocks are different.

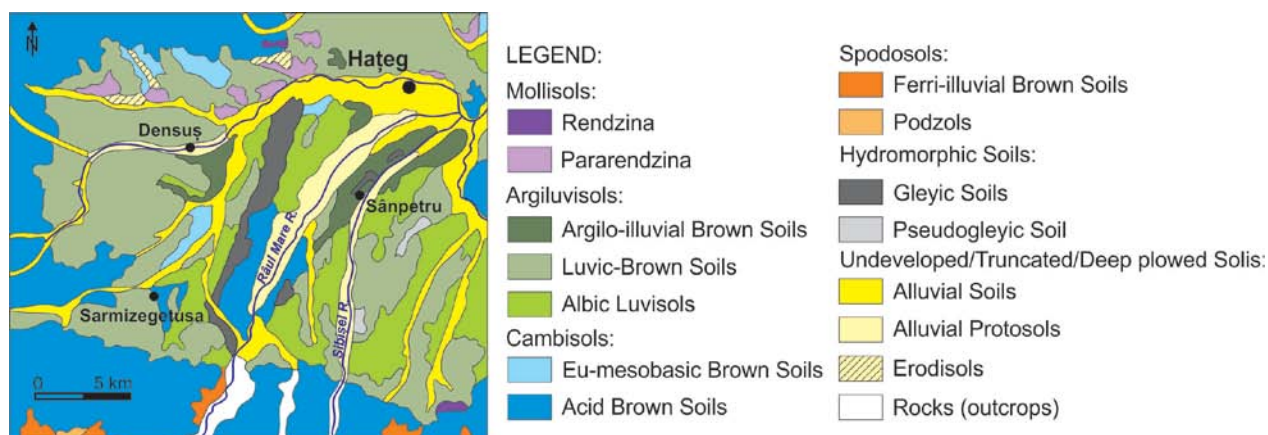


Figure 1 – Soil map of Hateg region, Romania (after FLOREA & BĂLĂCEANU, 1990, modified).

Table 1

RSST-1980		RSST-2003	
Class	Type	Class	Type
Argiluvissols	Argillo-illuvial Brown Soils BD	Luvissols LUV	Preluvissols EL
	Luvic-Brown Soils BP		Luvosol LV
	Albic Luvisols SP		
Cambisols	Eu-mesobasic Brown Soils BM	Cambisols CAM	Eutricambosol EC
	Acid Brown Soils BO		Dystricambosol DC
Mollisols	Rendzina RZ	Cernissols CER	Rendzina RZ
	Pararendzina PR		Phaeozem FZ
Spodosols	Ferri-illuvial Brown Soils PB	Spodosols SPO	Prepodzol EP
	Podzols PD		Podzol PD
Hydromorphic Soils	Gleyic Soils GC	Hidrisols HID	Gleyosol GS
	Pseudogleyic soils PG		Stagnosol SG
Undeveloped/ Truncated/ Deep plowed Soils	Alluvial Soils SA	Protosols/ Anthrissols PRO/ANT	Aluviosol AS
	Alluvial Protosols AA		Erodosol ER
	Erodissols ER		Rocks
	Rocks (outcrops) Z		

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## SOIL EROSION ASSESSMENT IN PIEDMONT: A TERRITORIAL APPROACH UNDER THE RURAL DEVELOPMENT PROGRAM.

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**KEY WORDS:** soil erosion, RUSLE, agro-environmental measures, Rural Development Programme.

### INTRODUCTION

Soil erosion in Piedmont is the most relevant threat, among those identified by the European Union in the "Soil Thematic Strategy". This threat particularly affects hilly soils in the Tertiary Basin of Piedmont, located between Turin and the Liguria region. In this area soil erosion has heavy effects on agriculture production triggering other soil degradation processes (i.e. organic matter decline, landslides, decline in biodiversity).

Soil conservation can be achieved by spreading conservation practices according to the Common Agricultural Policy and the Rural Development Programmes (CAP and RDP). These practices can be most effective if their implementation is based on the territorial impact of soil erosion on agricultural lands.

Since the 2007-2013 RDP, the Piedmont region has been studying soil erosion rate and developing the Soil Erosion Map as a tool to scale some agro-environmental measures based on erosion intensity.

### METHODOLOGY

The soil erosion rate has been estimated by using the RUSLE (Revised Universal Soil Loss Equation, Renard K. G. et al., 1997) which predicts the annual soil loss from sheet and rill erosion under defined conditions:

$$A = R \cdot K \cdot L \cdot S \cdot C$$

where:

A: Annual Soil Loss ( $t \cdot ha^{-1} \cdot year^{-1}$ );

R: Rainfall-Runoff Erosivity Factor ( $MJ \cdot mm \cdot h^{-1} \cdot ha^{-1} \cdot year^{-1}$ );

K: Soil Erodibility Factor ( $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$ );

L: Slope Length (dimensionless);

S: Steepness Factor (dimensionless);

C: Cover-Management Factor (dimensionless).

The RUSLE equation is the most used model to evaluate soil erosion rate in Europe at different scales, mainly thanks to the availability of input datasets.

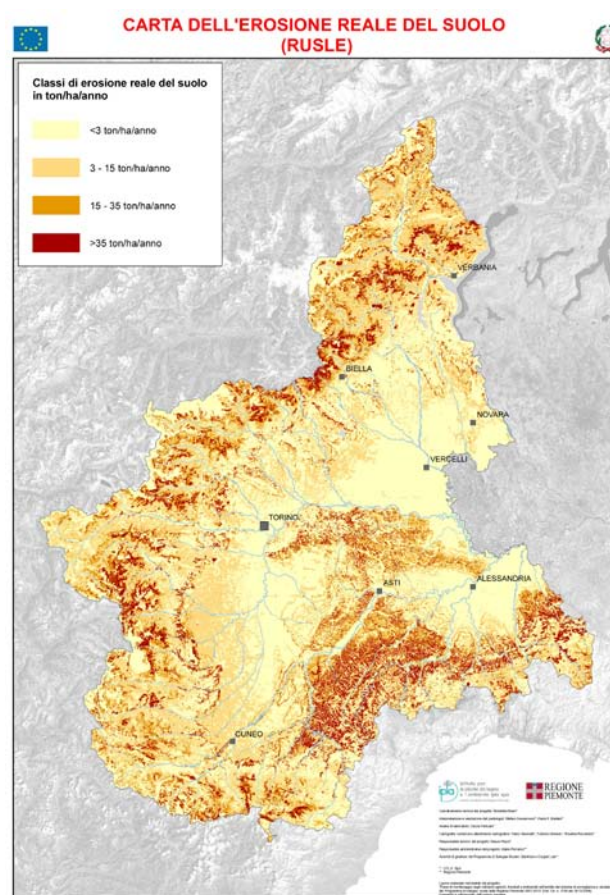


Figure 1 – Soil Erosion Map 1:250.000 scale.

The Soil Erosion Map has been realised starting from the geographical units of the Piedmont Soil Map at 1:250.000 scale (Boni, I. et al., 2007). The soil database contains more than 11.000 soil survey observations whereof 3.600 are soil profiles homogeneously located on the overall region.

The soil erosion rate has been represented by using a square grid of 100 metres on each side. Every factor of the RUSLE equation has been modelled by using this grid system, even though originally represented in different data formats:

- ✓ **K** is calculated from the analysis of the soil profiles from the Regional Soil Information System. The range of the well-known RUSLE nomograph for soil erodibility has been extended to fit soil texture - when the sum of very fine sand and silt is greater

- than 70% (Gregori E. et al., 2005) - and high organic matter content (Dissmeyer G.R., 1981).
- ✓ **R** derives from the dataset elaborated by Bazzoffi (2007) for Italy by using rainfall data of the last thirty years.
  - ✓ **L** and **S** factors have been calculated using the Digital Elevation Model elaborated by ISPRA with a square grid of twenty meters on each side.
  - ✓ **C** has been evaluated on the base of the Regional Land Cover Database at 1:50.000 scale (I.P.L.A., 2002). The C value has been defined for every land cover category according to the methodology proposed by Bazzoffi P. (2007).

By overlaying these different layers of factors, raster calculation allows to obtain a soil erosion rate for every single pixel of the final grid that has been classified into four classes according to the OECD proposal.

Subsequently the soil erosion layer has been intersected with cadastral layers to assign a soil erosion class to every cadastral geometric unit. This result has been achieved assigning the most recurrent erosion class for every single cadastral unit. By this way a new thematic layer on soil erosion has been added to the Regional Land Register, allowing the management of conservative practices in the RDP.

## RESULTS AND APPLICATION

The first result of the RUSLE application on the overall Piedmont territory is the evidence of soil erosion intensity in the three main morphological regional areas, as shown in figure 2.

Soil Erosion [t/ha*y]	Plains [ha]	Hills [ha]	Mountains [ha]	%
<3	676.787	137.295	414.425	48,7
3-15	251.345	102.580	458.044	32,2
15-35	30.614	75.935	155.876	10,4
>35	18.675	85.463	113.735	8,6

Figure 2 – Soil erosion classes in the three main morphological areas of the Piedmont region.

These values are equivalent to an average annual soil loss from 0,29 mm on alluvial plains to 1,53 mm on hill-slopes in the Tertiary Basin.

The map shows remarkable differences of soil erosion rate related to land variability. Soil erosion is obviously low on alluvial plains; it affects mainly the old terraces where soil erodibility is higher due to the high content of silt and very fine sand.

Considering the data shown in figure 2, mountains are the regional area where soil erosion affects the largest territory. Nevertheless most of these areas are so remote and slopes are so steep that soil erosion must be considered unavoidable.

On the other hand the average soil loss on mountains is 0,95 mm/year, that is considerably

lower compared to the mean value for hill-slopes of the Tertiary Basin.

Therefore hilly soils of the Tertiary Basin are the most affected by soil erosion due to higher soil erodibility, steepness and usual agricultural cultivations (vineyards and hazelnut plantations) characterized by reduced soil cover. Moreover in this area soil erosion can be mitigated by introducing measures of erosion control in agricultural practices.

According to this approach, some agro-environmental measures of the RDP 2007-2013 has been projected according to criteria of geographical priority, assigning a higher score to the applications regarding the most eroded lands.

These measures are:

- ✓ 214.1 and 214.2: grassing of vineyards and orchards;
- ✓ 214.3: increase of soil organic matter;
- ✓ 214.6: sustainable management of pastures;
- ✓ 121: soil arrangement technologies.

Soil erosion classification has been used as well during ex-ante and ex-post RDP evaluation, to assess the effectiveness of practices on soil erosion control.

Furthermore hilly soils of the Tertiary Basin have high economic value for agriculture products (Barolo and Barbaresco wines, truffles, etc.) and an unique landscape, recently included into the World Heritage List by UNESCO.

Finally a Soil Erosion Map at 1:50.000 scale has been realized, according to the RUSLE method and using a square grid of 20 m, almost on the overall area of the Tertiary Basin, by pedological in-depth analyses which integrated the previous soil surveys. This methodology implements now the new RDP, by helping to steer measures according to a geographic approach, in order to maximize the effects of practices on soil erosion control in the targeted areas where the soil erosion threat is greater.

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## ASSESSMENT OF SOIL QUALITY RESTORATION IN A CRONICALLY POLLUTED AREA TREATED WITH COMPOST BY COMBINING DIFFERENT SOIL INVESTIGATION TECHNIQUES

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**KEY WORDS:** soil quality restoration, compost treatment, PCBs, heavy metals.

### INTRODUCTION

Land degradation processes like organic matter impoverishment, loss of biodiversity and contamination are among the main threats to soil quality. The use of organic amendments positively influences soil chemical reactions such as pollutant degradation, sorption, precipitation and complexation that play a key role in mitigation of environmental risks. The compost has been demonstrated to be useful to assist natural soil remediation because enhances microbial activity, plant colonisation and development and thus promotes a restart nutrient cycling in degraded soils (Madejon *et al.*, 2006).

In this study an integrated approach, which combines chemical and microbiological investigation techniques, was developed in order to assess the soil quality restoration of a historically contaminated site after a compost treatment.

### MATERIALS & METHODS

The study site is a degraded area of  $\approx 4,5$  Ha located in Taranto city (Southern Italy) affected by wastes and pollutants: predominantly heavy metals and lightly PCB (Figure 1).

A treatment with compost (produced from selected organic wastes) was performed on a limited portion of the study site (box in Figure 1) with the aim to improve soil quality restoration. Three acquisition data campaigns were carried out:

**C** - (September 2012): *characterization campaign*

**J** - (June 2013): *1<sup>st</sup> monitoring campaign* (4 months after compost treatment)

**S** - (September 2013): *2<sup>nd</sup> monitoring campaign* (7 months after compost treatment).

#### Soil chemical analyses

During every survey campaign, about 20 topsoil (0-20cm) samples have been collected from the site (box in Fig.1) and analysed to determine the main physico-chemical properties: texture, pH, organic carbon, total nitrogen, available phosphorous, carbonate and water content.

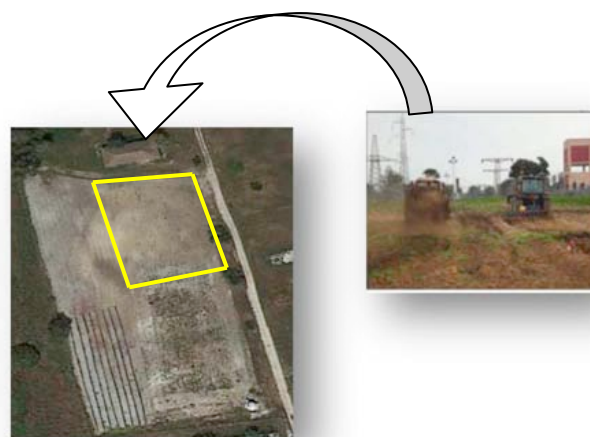


Figure 1 – Study site

#### Pollutants investigations

Analytical investigations were conducted on soil samples of the survey campaigns. Organic pollutants (PCBs) analyses were performed by **GC-MS** (Thermo Scientific Finnigan TRACE GC ultra) equipment, while heavy metals screenings were carried out through **ICP-MS** instrument (Agilent 7700 Series).

#### Microbiological analyses

Structure and functioning of the bacterial community have been investigated on soil subsamples by evaluating the: Bacterial Abundance (DAPI counts) and, Dehydrogenase Activity (DHA).

#### Data analysis

The assessment of soil environmental quality in the compost treated site, was carried out as follows: firstly, a Pollution index ( $Pi=C_i/C_i^{ref}$ ) was calculated for each of the N metals, where  $C_i$  is  $i^{th}$  metal concentration in each sample and  $C_i^{ref}$  is the Italian law limit (D.Lgs. 152/06); then, the Mean Pollution Index (MPI) was calculated following the approach proposed by Abraham & Parker (2008), where the final index is obtained by the arithmetic average between the N metals.

Moreover, statistical evaluations of laboratory chemical analyses - Hierarchical Cluster Analysis (HCA) based on Principal Component Analysis (PCA) - have been performed using STATGRAPHICS Centurion for Windows.

**RESULTS & DISCUSSION**

Table 1- Average concentration of pollutants determined in soil samples of the both survey campaigns.

Italian law limit (D. Lgs. 152/06)	Be	V	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Hg	Tl	Pb	PCB
C (Sept-12)	<b>3,9</b>	<b>130,0</b>	<b>221,3</b>	17,1	96,7	45,1	<b>263,2</b>	<b>23,2</b>	<b>14,3</b>	0,7	<b>76,6</b>	<b>18,7</b>	1,0	0,8	<b>147,3</b>	<b>235,15</b>
J (June-13)	1,7	60,3	50,8	8,0	37,8	17,8	142,7	11,4	2,0	0,3	<b>3,8</b>	0,9	0,4	0,5	28,2	49,16
S (Sept-13)	1,7	59,4	48,9	7,7	35,4	19,0	143,0	11,2	1,6	0,3	<b>5,6</b>	1,3	0,5	0,5	32,0	-

Soil chemical analyses revealed a major increase of all the nutrient elements (C, N, P) after 7 months from compost treatment (data not shown). The average concentration of inorganic and organic pollutants drastically decreased under the Italian Law thresholds (D. Lgs. 152/06) in soil samples of the monitoring campaigns (June and September 2013), as evidenced in Table 1.

On detailed, after the compost treatment a consistent reduction of the PCB congeners in higher content of chlorides (118,153,138,180) was observed. Moreover, the Mean Pollution Index calculated for the heavy metals dataset revealed that a considerable decrement of inorganic contamination was observed already after 4 months from the treatment with compost (Figure 2).

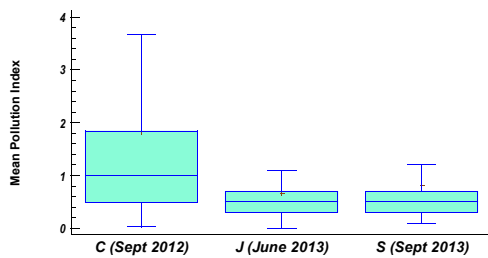


Figure 2 - Mean Pollution Index

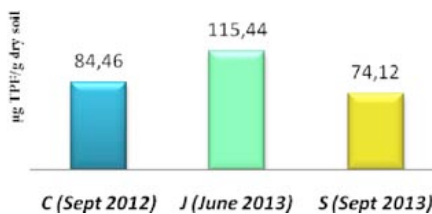


Figure 3 - Dehydrogenase activity (DHA)

Microbiological investigations evidenced a relevant increase of Microbial Abundance in the soil samples of the first monitoring campaign (on June 2013) while a diminution was registered after 7 months from the recovery treatment with the organic amendment. Similarly, dehydrogenase activity (DHA) of bacterial community revealed the highest values in soils sampled in June 2013, as evidenced in Figure 3.

The HCA identified four soil groups in the different periods of investigation (C, J, S). Soil samples collected during the characterization campaign (C, on Sept 2012) have been mainly grouped in a big class (green box), while soils collected in June 2013 are divided in two groups which differing in the inorganic pollution levels (violet box in Figure 4). Lastly, a fourth soil group, which enclosed the samples collected after 7 months from compost treatment, characterized by very low pollution and elevated values of nutrient elements, was evidenced by HCA based on PCA of soil chemical analyses. These statistical evaluations, according to microbial results support the hypothesis that a soil quality restoration process was occurring in the treated site as induced by compost addition. Further investigations are needed to understand the possible mechanisms underlying the restoration of soil quality in the investigated area.

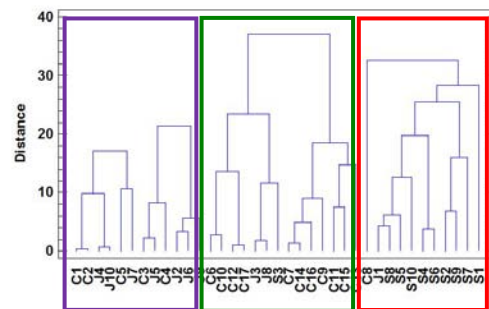


Figure 4 - Cluster Dendrogram

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## HAND-HELD XRF – A CONTRIBUTION TO IMPROVE SOIL SAMPLING STRATEGY?

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**KEY WORDS:** hand-held XRF, soil sampling strategy, aqua regia, soil moisture

### INTRODUCTION

Defining areas with geo(anthropo)genic elevated heavy metal content in (top)soils in scale 1:10.000 or higher need a dense grid for soil sampling. Geo(anthropo)genic elevated Pb content in soils around Freihung threatens agriculture and groundwater. Can field measurements by hand-held XRF support soil sampling strategy for necessary analysis in aqua regia extract according to German Federal Soil Protection Ordinance (BBodSchV, 1999)?

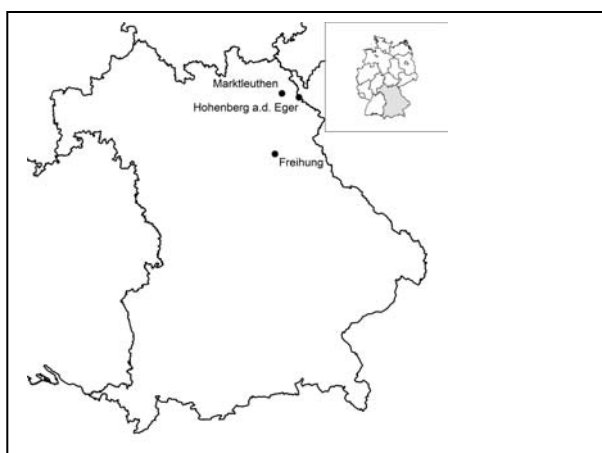


Figure 1 – Investigated areas in Bavaria.

### MATERIAL AND METHODS

- A 100m x 100m grid placed over relevant stratigraphies of 'Benkersandstein' (Keuper) (cerussites, galenite) around Freihung totalling in 190 topsoil sample sites.
- At each sample site a soil pedon (0,15m x 0,15m x 0,3m) was dug up with a spade. Three measurements by hand-held XRF (NITON XL3t, Analyticon Inc.) covered the whole depth interval of one side of soil pedon. The averaged value of these three measurements was used for statistics.
- At five semiterrestrial and six terrestrial sites (subarea Tanzfleck) composite samples were taken for comparative aqua regia analysis.
- Correlations between aqua regia (y) and hand-held XRF (x) for Pb and Zn of these 11 sample sites were

calculated separately according to groundwater influence.

- To elucidate the effect of soil moisture upon XRF-measurements, 79 steel-ring soil samples taken at the riparian zone of the river Eger at 4 sites between the communities of Markt-leuthen and Hohenberg a.d. Eger (Fig. 1) were dewatered at the pressure steps - 63 hPa (pF 1,8), -316 hPa (pF 2,5), and -15849 hPa (pF 4,2) and the soil moisture noted. Afterwards mXRF-measurements (NITON XL3t) were carried out taking 30 seconds per measurement. Due to logistic constraints undisturbed oven-dried samples could not be measured using the mXRF.

### RESULTS

Given the low sample size, the correlations between aqua regia (y) and hand-held XRF measurements (x) for the elements Pb and Zn show acceptable results (Fig. 2). Separating the sample sites according to groundwater influence even improve the results. Ground water/soil moisture seems to affect the quality of measurements by hand-held XRF, which should be considered.

Pb		
sample sites (n =11)	$y = 0,6422x$	$r = 0,83$
terrestrial sites (n = 6)	$y = 2,0272x$	$r = 0,97$
semiterrestrial sites (n = 5)	$y = 0,6407x$	$r = 0,57$
Zn		
sample sites (n =11)	$y = 1,4024x$	$r = 0,72$
terrestrial sites (n = 6)	$y = 1,2137x$	$r = 0,98$
semiterrestrial sites (n = 5)	$y = 1,4053x$	$r = 0,57$

Table 1 – Correlations for Pb and Zn.

In consequence, translation of hand-held XRF measurements of Pb and Zn to aqua regia for the subarea Tanzfleck seems to be possible, in particular for terrestrial sites.

### EFFECT OF SOIL MOISTURE ON XRF-SIGNALS

Although other influencing factors, e.g. mineralization heterogeneity, surface unevenness and matrix effects (Ge et al., 2005), were not considered here, there is a marked decrease of XRF-signal due to soil moisture as exemplified for the sampling site Hebanz and Schwarzenhammer.

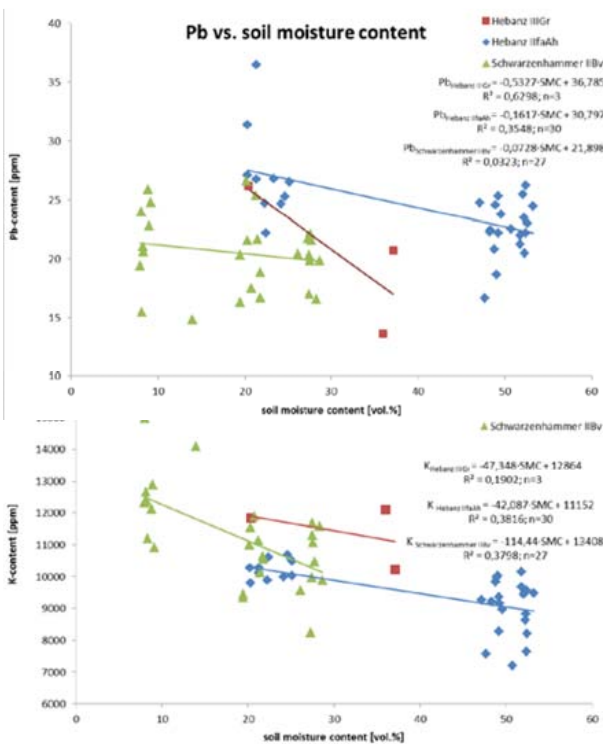


Figure 2 – Moisture dependent XRF-signals exemplified for lead (Pb) (top) and potassium (K) (bottom) of three riparian soil horizons. “SMC” means soil moisture, “R<sup>2</sup>” is measure of determination, and “n” is sample number.

Presumably, water in soil absorbs the characteristic X-rays from the elements and also leads to a scatter of the primary radiation from the excitation source (e.g. Bastos et al., 2012). By taking the intercept of the tentative regression equations, the real metal content can be approximated (Fig. 2). In contrast to other studies, which state that the water content is effective mainly for metals with atomic numbers (AN) < 26 (Ge et al., 2005), we found such an effect for the light potassium (K) (AN=19) as well as for the heavy lead (Pb) (AN=82). The influence of soil moisture upon the XRF-signal is reported to vanish at water contents <20 vol.% (US EPA, 2007). However, at the site Schwarzenhammer a clear increase of the Pb- and K-signal occurs also at a low soil moisture content of about 10 vol.% (Fig. 2). For this, a complex of further factors such as fine pore fraction for the Pb-, and the bulk density for the K-content (Tab. 2) could indirectly affect soil moisture distribution and thus the XRF-signal.

		kf [cm/d]	fine pores [%]	medium pores [%]	narrow wide pores [%]	wide pores [%]	bulk density [g/cm <sup>3</sup> ]
Pb [ppm]	SC	-,214	,633	-,317	-,126	-,100	-,067
	Sig	,610	,067	,406	,748	,798	,865
	n	8	9	9	9	9	9
K [ppm]	SC	,429	,017	,200	-,100	,567	-,667
	Sig	,289	,966	,606	,797	,112	,050
	n	8	9	9	9	9	9

\*correlation significant at 0,05-level

Table 2 – Correlations between measured Pb- and K-contents and potentially influencing soil parameters of IIbV-horizon in Schwarzenhammer. SC= Spearman-correlation coefficient, Sig=level of significance, n=sample number.

**CONCLUSIONS**

Grid based screening of the area under investigation by hand-held XRF measurements and in low scale (about 20 % of total sites) additional expert selected soil sampling for wet chemistry analysis seems to support by calculating correlation XRF – aqua regia and translation XRF data to ‘pseudo’aqua regia. Soils texture and soil parent material are assumed to also influence XRF measurements. Also soil moisture has a pronounced effect upon XRF-signals. In XRF-screenings this should be taken into account to allow for a retrospective moisture correction (e.g., Bastos et al., 2012).

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## SOILS, GIS AND WINES

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**KEY WORDS:** Soil, Maps, Wine, Terroir, GIS, Sustainable development

### THE TERROIR

The term *terroir* reveals more than one single meaning. From a geological point of view, it involves many morphological components of the landscape such as bedrock, soil composition, slope shape, steepness, exposure, weather conditions. In this case, the study of the most important Italian wine's "terroir", can be performed by analyzing the territory of production, using GIS, as already successfully used in environmental studies aimed at the sustainable use of the territory: this approach is also interesting in terms of popularization, considering the link between nature and culture symbolized by wine in the Italian tradition.

Another definition of terroir states that it is a homogeneous part of biosphere, recognizable by stable values of terrain, climate, soil and subsoil, strongly characterized by the variation of the concentration of the soil components.

The chemical and isotopic composition of the inorganic matrix is tied to the geologic material of the soil in which the vines grew. So, the geochemical analysis of some elements allows to verify the effective origin of the wine, providing indisputable proof of its authenticity: an important weapon against counterfeiting. For example the Strontium isotope analysis helps to perform a viticultural zoning and geographical traceability of some fine wines.

The economic and social components that in the field of food and wine activate the mechanisms of marketing, have recently been focusing the attention on a new "image" of wine, investing new energies in this direction. In this context, however, the territorial contextualization appears not exhaustive enough, referring to the link between the environment in the places of production and the characteristics of each wine: the DOC areas ("Denominazione Origine Controllata": mark guaranteeing the quality of a wine) are identified at the administrative level of municipality so they don't represent the true spatial distribution of vineyards; nevertheless they testify the vocation of the corresponding territory.

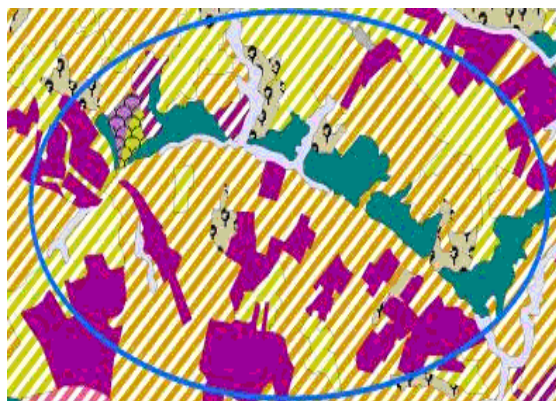


Figure 1 – CORINE Biotopes Map of the Atri area (the box in the following figure) Abruzzo region

Wines are a significant sign of the territory and the role of the "geologist sommelier" can offer new ways to learn about the wines, studying the natural arrangement of the territory of origin, and the history of production.

The organoleptic analysis may be related to the geo-environmental elements, if framed in a proper integrated approach. The cultural themes in touristic journeys can be enriched with some scientific information on the physical-chemical characteristics of the soils, that give the wine its own taste; the customers and the consumers can recognize and feel this link: they will be able to find the land in its wine. In this sense, the oeno-gastronomic tourism offers new chances, referring to the link among the earth and its products

### THE PRESERVATION OF THE VINEYARD LANDSCAPE

The Italian landscape is characterized by a lot of old rural landscapes and abandoned cultivation, particularly in some peri-urban natural areas in the south of Italy. The restoration of a degraded land can in some cases be made up performing the re-establishment of those areas traditionally devoted to vineyard cultivation. An integrated study of the territory by the GIS and the related thematic maps, may allow the identification of the rural historic landscape and helps planning activities, for an effective preservation of the special fusion of nature and culture characterizing the country. A first recognition on the territory can be performed by following a multi-scale approach: in

first place, by the Soil Map of Italy and the Geologic one (1:1,000,000 scale)

At a more detailed scale, the analysis of the distribution of vineyards can be performed by integrating the Land Cover map (CORINE classification - 1:100,000 scale) and the two main products of the the "Carta della Natura" project; the Physiographic Units map (1:250,000 scale) and the Habitat map (CORINE Biotopes/EUNIS - 1:50,000 scale). Starting from the link between vineyard cultivation, soil profile and geomorphological settings, it is possible to analyze the possible evolution of the vineyard cultivation and wine production, so that one can try to get the best sustainable development of the area; an

experiment to integrate cultivations and culture, in a local approach, can be realized by trying the replanting of old vines in protected areas.

It must not be disregarded the fact that soil functions are strictly connected to biodiversity, so that the progressive soil consumption we are facing, correspondingly brings along a biodiversity loss, with presently unpredictable effects on life on earth. Framing this consideration in the main topics of this contribution, we see that is extremely clear that a detailed soil mapping of areas with a specific vocation to wine production would foster sustainable development and optimal growth of local and regional economy and life standards.

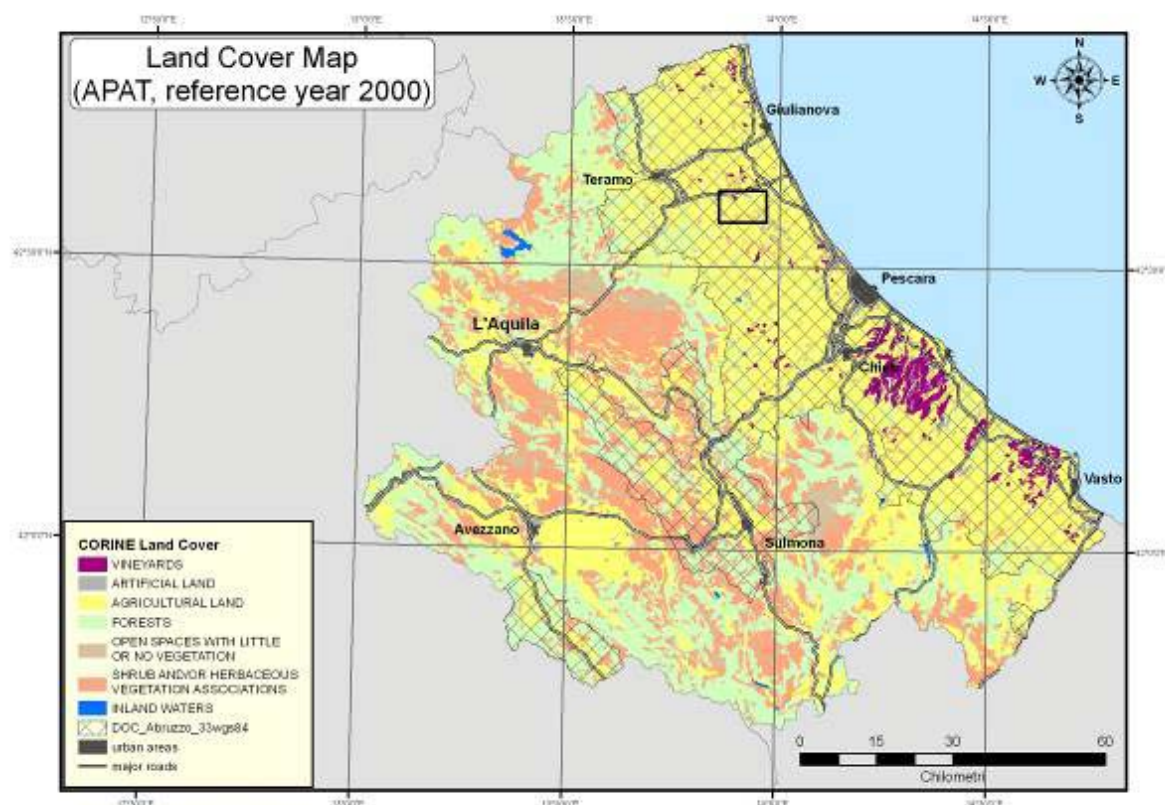


Figure 2 – CORINE Land Cover map of Abruzzo region and DOC Wine Production Areas and vineyard distribution (the box indicates the area of the case study, near Atri).

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## SPATIAL DISTRIBUTION OF TOPSOIL ORGANIC CARBON IN CROATIA

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**KEY WORDS:** soil organic carbon, LULUCF, carbon stocks, karst, soil, Croatia

### INTRODUCTION

Changes in soil organic carbon (SOC) stocks in Croatia were recently estimated based on available data from the basic soil map of Republic of Croatia (OPK-RH), which was compiled during the period between 1964 and 1985 (PILAŠ et al., 2013). Using the soil organic carbon data from the soil mapping program and the Corine Land Cover inventories in 1980, 1990, 2000 and 2006, PILAŠ et al., estimated that soil organic carbon stock in Croatia for all CLC categories relevant for the LULUCF sector (93% of the total country area in 2006) is 618,77 Mt. Forests and areas with natural vegetation with 348,11 Mt. Estimated soil carbon stock in agricultural land is 270,46 Mt, of which 166,99 Mt contain classes of intensive agriculture (arable land, permanent crops and complex cultivation patterns). Total change in SOC stock between 1980 and 2006 was estimated to +1.91 Mt and is mostly due to changes in agricultural practices in rural areas (PILAŠ et al., 2013).

In order to improve the data and to have a better spatial resolution the archived soils from the Croatian Geochemical Mapping Program (from 1991-2002) established on a 5 km×5 km grid and provided 2470 new measurements of stocks of soil organic carbon, obtained through an in situ composite sampling, uniformly distributed over whole Croatian territory. Also the analysis of Ca and Al from the geochemical campaign also allow estimates of inorganic carbon (IC) in Croatian soils. Changes in soil carbon stock resulting from formation or dissolution of carbonates are required for establishing IC concentrations and stocks since this is an important carbon pool in certain parts of Croatia.

### STUDY AREA AND METHODS

The Republic of Croatia covers 56,538 km<sup>2</sup>, and a population of 4,5 million, in south-eastern

Europe is characterized by a complex geological framework. The territory of Croatia in a regional geological sense is subdivided into two major geological units, the carbonate (karst) terrains and the northern clastic Pannonian basin (marls, sandstone, sand, clay and gravel). Soils developed on these bedrocks are dominated by automorphic soils (56%) consisting of luvisols, cambisols (eutric, district, rhodic) leptosols, and hydromorphic soils (29%) in the Pannonian region (stagnosols, fluvisols, gleysols, hydroameliorated soils). About 14 % of Croatian territory is exposed bedrock lacking soil cover mainly in the karst region (BAŠIĆ, 2005). The dominant CLC class in Croatia are forest and woodland areas which occupy 46.8% of 5. 658. 465 ha total land, followed by heterogeneous agricultural areas with 32.6%, shrubs and herbaceous vegetation 8.4%, arable land and permanent crops 7.8%, artificial surfaces 3.1%, wetlands 0.4%, and freshwater areas 1,0% (PILAŠ et al., 2013).

Soil samples were air-dried, ground, and passed through a 2-mm mesh sieve. Visible plant residues, gravel, and stones were removed manually. The C and N contents in the fine earth (>2 mm) were determined by ThermoFlash SOIL CN Elemental Analyzer, which employs the dry combustion (DC) method. Since Croatian soils frequently contain carbonates the carbon content was also determined on soils after removal of carbonates (after treatment with HCl).

### ORGANIC CARBON DISTRIBUTION

Moors and heathlands with SOC density of 122.9 t C/ha have the highest mean SOC densities. The distribution of SOC shows that the Pannonian part of Croatia (1-2%) has in general 3 times lower SOC concentrations in the topsoil (4-6%) and highest mean SOC densities are found on cambisols in the karst region. The SOC stock in forest ecosystem classes have the mean SOC density (from 103 and 118 t C/ha). In general arable soils have lower (82.9 t C/ha) SOC density than pastures (91.6 t C/ha). Among the forest

ecosystem types, conifer forest shows the highest SOC density (118.9 t C/ha). The C:N ratio is considered as an indicator of nitrate leaching and is lowest in the arable soils in the northern Pannonian region. Main difference in carbon storage between Pannonian (SOC density 85 t C/ha) and Mediterranean (karst) soils (108 t C/ha) is related to the soil depth. Carbon content in samples taken from Mediterranean environment is higher in average, but overall carbon storage is higher in soils from Pannonian region because of small soil depth and the high stone content of coastal karst soils. The average SOC density of karst mountainous soils is 118 t C/ha.

Table 1. Organic carbon stocks in Croatian topsoils in CLC categories relevant for the LULUCF sector.

clc description	N (number of sites)	C stock in soil layer in t C/ha (means)
arable land	391	82.91
fruit trees	61	117.33
vineyards	5	110.79
coniferous forest	117	118.84
broad-leaved forest	785	103.20
mixed forest	117	114.37
transitional woodland-shrub	18	97.77
pastures	448	91.60
moors and heathlands	86	122.39
natural grasslands	349	112.17
continuous urban fabric	6	76.93
green urban areas	12	93.74
olive groves	12	141.39
Mean	2470	106.42

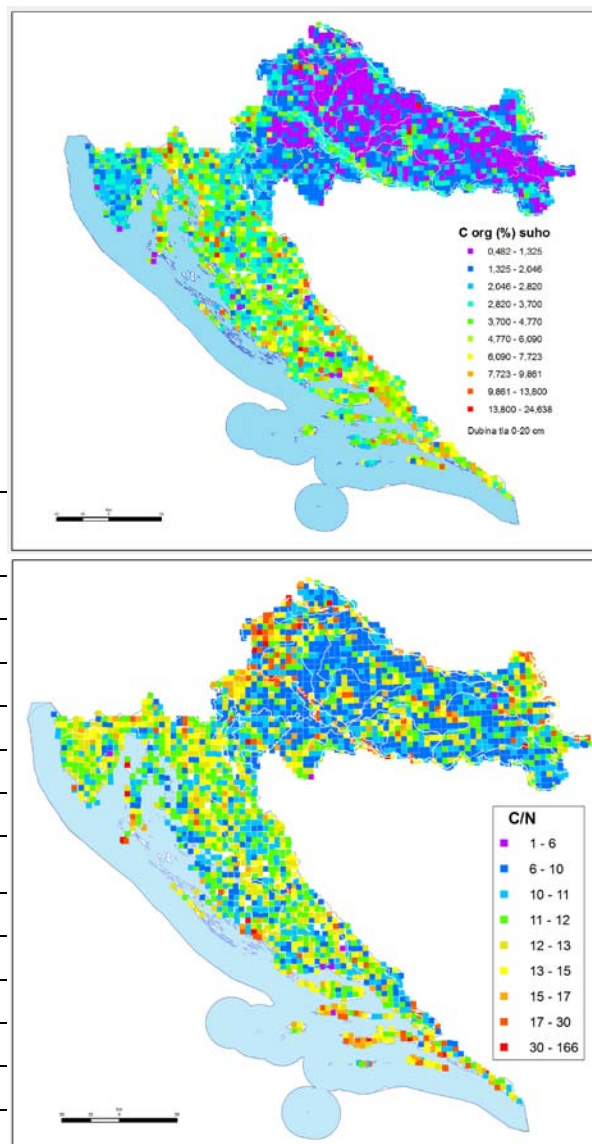


Figure 1 – Distribution of organic carbon and C:N ratio in topsoils from Croatia

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## MULTISCALAR APPROACH TO ASSESS THE ENVIRONMENTAL GEOCHEMICAL RISKS FROM TOPSOILS IN THE CAMPANIA REGION (ITALY)

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**KEY WORDS:** *environment, risk assessment, soil, Campania.*

### INTRODUCTION

Environmental risk assessment is an issue widely diffused in the international scientific literature (Albanese et al. 2014) and extremely topical for preserving human health and natural ecosystems. The main purpose of risk assessment is the probabilistic evaluation of damages on humans and environment coming in contact with one or more contaminated environmental media (soil, water, air, sediments, etc.). The general concept of environmental risk is expressed by the equation  $R = H * E$  (Ropeik and Grey, 2002), where H is the hazard generated by the presence in the environment of one or more potentially toxic substances; while E is the Exposure, expressing the effective possibility for humans to come in contact with the toxic substance released by the contaminated media. This type of risk assessment was done, until now, at local level, due to the extremely high variability of some parameters involved in the risk evaluation. The object of this work is to implement the environmental risk assessment procedure at a regional level, in a prospective mostly oriented to the safety of human health, by taking into account also the actual population exposure, besides the distribution and degree of contamination. This procedure will allow a better management of environmental risk at regional scale by minimizing costs, and selecting priority areas, where possible remediation actions should be taken; in those areas classic health risk assessments will be performed in detail.

### METHODS

3535 top soils (10-15 cm depth) were collected over the entire Campania region with a density of 1 sample/4 km<sup>2</sup>, following the international guidelines (Salminen et al. 1998). The samples were analyzed at ACME Analytical Lab. Ltd (Vancouver, Canada), to determine the concentration of 52 elements (Ag, Al, As, Au, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, Hg, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Pd, Pt, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Te, Th, Ti, Tl, U, V, W, Y, Zn, Zr) with a combined

methods of ICP-MS and ICP-ES by a preliminary aqua regia digestion. Precision and accuracy of measures were evaluated using sample duplicates and analytical standards analyses.

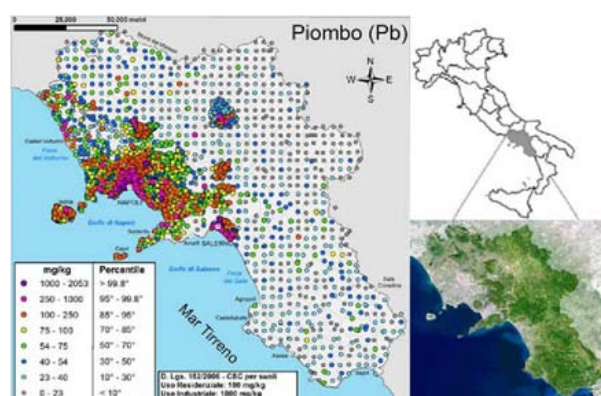


Figure 1 – Dot map for Lead (Pb).

The obtained data were organized in a database, associating at every sample an ID code, the geographical coordinates (WGS84) and the analytical result for each considered element.

The statistical analysis of data was performed by means of Kaleidagraph<sup>TM</sup> software, with the production, for every element, of summary tables reporting the main statistical parameters (maximum and minimum value, average and modal values, median, standard deviation), histograms, box plots and cumulative curves. The cartographic elaboration led to the production of dot maps (Figure 1), interpolated maps and background maps, using ArcGIS<sup>TM</sup> software. Concentration values in the dot maps were classified studying the trend of the cumulative curves; seven or eight intervals, depending on the case, were established identifying the breaks of slope and/or appropriate percentiles (10° fixed; 25°, 50°, 70°, 90°, 95°, 97.5° fixed, or near if evident breaks of slope occurred).

The spatial interpolation of chemical data was carried out using the Multifractal-IDW method (Cheng et al., 1994; Lima et al., 2003), implemented by GeoDAS<sup>TM</sup> software. Each pixel within the interpolated maps measures 2500 m x 2500 and the interpolation radius was fixed at 5 km. GeoDAS<sup>TM</sup> was used also to reclassify the interpolated surfaces using the C-A

(concentration-area) plot method; this method uses breaks of slope along the C-A plot to discriminate on the map groups of pixels characterized by a common behaviour in the spatial distribution of elemental concentrations.

Furthermore, in GeoDAS™ software, the S-A plot (Separation Analysis) method was also used in order to separate the background values from anomalies (Cheng, 2001; Cheng et al., 1994).

Finally, to generate a map of the regional potential hazard distribution, the interpolated maps of some potentially toxic elements (Sb, As, Be, Cd, Co, Cr, Hg, Ni, Pb, Se, Sn, Tl, V, Zn), in accordance with the Italian environmental law (D.Lgs 152/2006), have been reclassified on the base of the trigger and action limits (CSC) for human safety established by this latter. Specifically, for each considered grid, the pixels assumed a new value of 1 if the concentration in that pixel was above the CSC value or a value of 0 if the concentration was below the limit. The obtained maps were summed up in a GIS environment in order to obtain a cumulative map of the potential hazard (Figure 2).

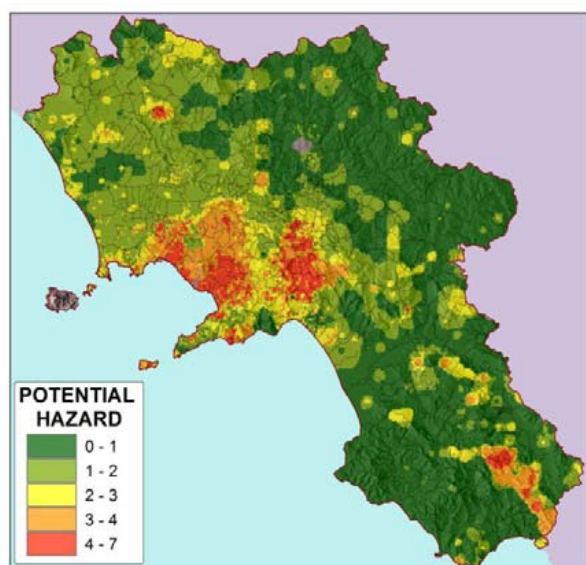


Figure 2 – Potential hazard distribution map.

## CONCLUSIONS

The produced potential hazard distribution map shows an environmental condition, which is potentially not tolerable for the resident population of the Campania region. In some areas, the concentrations of some elements overcome the corresponding CSC, suggesting the need of running a risk assessment procedure.

In these areas where the potential hazard was up to 7 at same time the established CSC, follow up prospecting activities should be planned and carried out to produce more detailed information to

better evaluate if there is a real risk for local population to develop health problems.

Land use and population distribution should be considered for the risk and to locate the areas in which a high demographic density could lead to a real improving of mortality.

New soil samples should be collected in correspondence with the most hazardous areas and a conceptual model (CM) of these areas should be developed to better understand which are the most effective exposition pathways followed by contaminants to reach the local population.

## ACKNOWLEDGEMENTS

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## HIERARCHICAL BAYESIAN SPATIAL MODELLING TO IDENTIFY AND MAP SPATIAL VARIATIONS OF SOIL PROPERTIES IN VITIVINICULTURAL ZONING STUDIES

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**KEY WORDS:** multilevel Bayesian splines methodology, soil properties, vitivinicultural soil mapping.

### INTRODUCTION

Vitivinicultural zoning studies are important to delimit a legally protected territory and to control technologically a viticulture area. In wine production, the soil is considered, together with climate, as a key component of Terroir (van Leeuwen et al., 2004) which can influence the wine quality (van Leeuwen and Seguin, 2006). The effect of the soil on vine behaviour and grape composition is complex, because the soil influences availability of major vine nutrients and water uptake conditions (Van Leeuwen and Seguin, 2006). Geostatistical methods provide a useful tool to describe the spatial distribution and variability of soil properties in vitivinicultural zones. The hierarchical Bayesian spatial models can incorporate known information about the parameters and the uncertainty (Banerjee et al., 2014).

Thus, the aim of this study was to evaluate the use of hierarchical Bayesian spatial models to differentiate vitivinicultural zones in regions based on the pedological parameters.

### MATERIALS AND METHODS

The work has been performed in the Vinalopo Region, which is 6,550 ha complex landscape located in the Southeast of Spain. This area has a high soil and climate spatial variability and it is a traditional setting for vineyards producing high quality wines including one DOC wine (Protected Denomination of Origin Alicante). The studied area was divided in nine traditional agricultural zones. 117 topsoil samples were collected from the different vineyard plots within the studied zones (Fig. 1), 20, 16, 5, 10, 10, 21, 13, 17 and 5 samples from the Zones 1, 2, 3, 4, 5, 6, 7, 8 and 9, respectively. The surface of the sampled plots ranged from 0.24 to 15.99 ha and with an

elevation between 265 and 675 m a.s.l. Samples were collected from January 2010 to December 2011, using stainless steel shovels and were stored in individual black plastic bags (darkness). Soils were sampled in depths from 0 to 20 cm. Each soil sample was air-dried, homogenised and sieved to 2 mm.

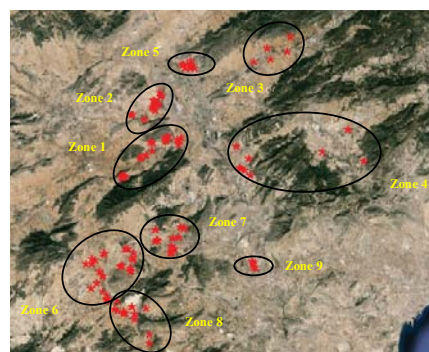


Figure 1 - Location of the sampling soils and the studied zones at the Vinalopo Region.

pH, electrical conductivity (EC), cation exchange capacity (CEC), contents of active calcium carbonate, organic matter (OM), gypsum, sand, clay and silt and the level of aggregate stability (AE) were determined according to Moreno-Caselles et al. (2003) methods.

In this work was used the Integrated Nested Laplace Approximations (INLA) by Rue et al. (2009), defined by:

$$Y_i \sim N(\mu_i, \rho_i), i = 1, \dots, n, \quad \mu_i = X_i \beta + W_i$$

$$\pi(\beta_i) \sim N(\mu_{\beta_i}, \rho_{\beta_i}); \quad W_i \sim N(0, \rho(\kappa, \tau))$$

$$2 \log \kappa \sim N(\mu_{\kappa}, \rho_{\kappa}); \quad \log \tau \sim N(\mu_{\tau}, \rho_{\tau}),$$

where  $Y_i$  represents the kilograde productivity,  $X_i \beta$  represents the linear predictor with relevant variables, and  $W_i$  the spatial effect.

### RESULTS AND DISCUSSION

The best model with lower DIC criteria was:

$$\log(KG) \sim 1 + \text{alt.} + \text{Sad}\% + \text{CaCO}_3\% + \text{gypsum} + W_i$$

Table 1 - Posterior distribution for the fixed effects of the model.

	Mean	SD	Q <sub>0.025</sub>	Q <sub>0.5</sub>	Q <sub>0.975</sub>
Intercept	10.388	1.778	6.875	10.395	13.868
Altitude	0.0011	0.0016	-0.002	0.0011	0.0042
CaCO <sub>3</sub>	0.0153	0.0271	-0.038	0.0686	0.0152
Sand	-0.005	0.0211	-0.046	-0.005	0.0368
Gypsum	-0.0220	0.3645	-0.7435	-0.021	0.6907

In the Table 1, the altitude and the CaCO<sub>3</sub> content showed positive values, but the sand percentage and the gypsum concentration had negative coefficient in relation to the “Kilograde” in the plots. The Credible Region showed that the fixed effect had little relevance over the kilograde in this area. For the spatial effect, this had an important presence. In the Figure 2, the behaviour of the posterior mean for the spatial effect is shown, which seemed to have a north-south effect.

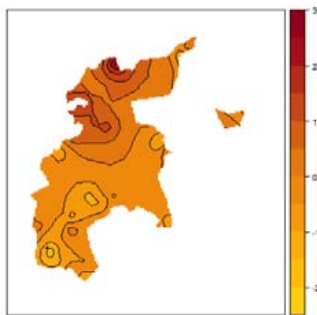


Figure 2 - The Mean for the Spatial Effect

Using this information, the predictive posterior distribution for the linear predictions for some determined parameters in the study area is shown in Fig. 3. The spatial prediction maps showed that the eastern part of the study area had a greater agricultural aptitude for the grape growing, according to soil properties suitable for producing quality wines (van Leeuwen and Seguin, 2006). This zone presented higher OM and AE levels and CEC values and lower active CaCO<sub>3</sub> content and EC and pH values. However, the northwestern part of the study area had saline soils due to important factors of soil formation; there are, the presence of Tertiary (Keuper) marls and clays with high content of calcium sulphates (gypsum or CaSO<sub>4</sub>·2H<sub>2</sub>O; anhydrite or CaSO<sub>4</sub>) and halite (or NaCl) (Juan et al., 2011).

Thus, this work has shown here the usefulness of Bayesian framework to analyse the form of the predictive spatial distributions of the soil properties considered in this study. The results of this geostatistical analysis can be applied in making decisions regarding vitivincultural land and production management and planning.

#### ACKNOWLEDGEMENTS

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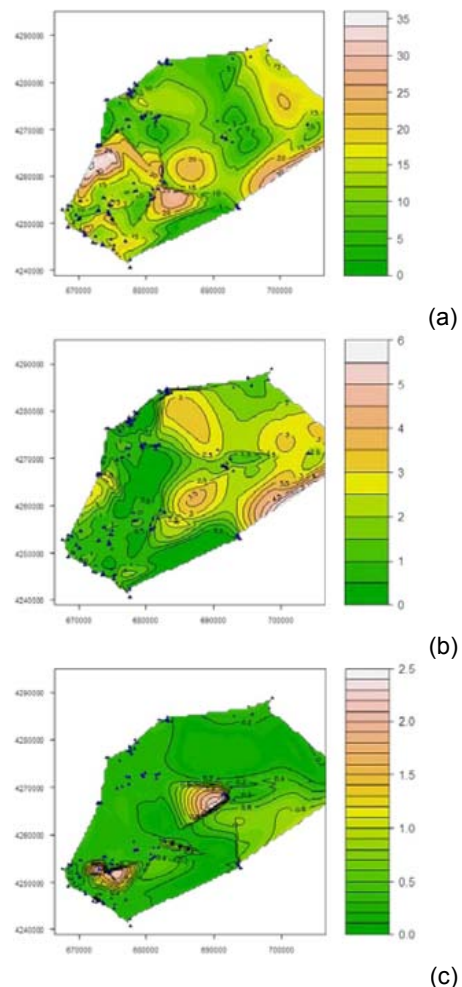


Figure 3 – The spatial prediction maps for the aggregate stability percentage (a); the organic matter percentage (b) and the electrical conductivity values(c).

## PRELIMINARY STUDY OF CHEMICAL FORMS OF Pb IN SEDIMENTS OF SAN SIMON BAY (NW, SPAIN)

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**KEY WORDS:** *Lead, anoxic sediments, sequential extraction.*

### INTRODUCTION

Ría de Vigo, located at northwest Iberian Peninsula, is a large submerged incised valley which is oriented SW-NE. San Simón is a shallow bay situated in innermost part. In this area, high density of population and industrial activities carried out, cause enormous pressure on these ecosystems.

The sediments can act as sinks of trace metal. Accumulations of metals in sediments pose environmental problems, especially in San Simón Bay where mussel farming is very important hence the toxicity of heavy metals requires some vigilance. Toxicity and mobility of these metals will depend on the chemical form in which the metal is found in nature.

In this work, the content and accumulation of Pb in the surface layers of San Simón Bay is investigated.

### MATERIAL AND METHODS

In San Simón Bay, at innermost part of Ría de Vigo, the high biological productivity combined with high sedimentation rates favor the development of anoxic conditions in the sediment, determining the speciation of metals.

A gravity core was collected in the subtidal area of San Simón Bay (Fig. 1) in November 2012 for the study of chemical forms of Pb.

Pb sequential fractionation was performed according to the method of Campanella et al. (1995) in which 5 fractions were obtained: Pb present in ion-exchange form and bound to the carbonate (F1), Pb present in the reductive phase bound to manganese-iron oxides (F2), Pb weakly bound to organic matter (F3), Pb strongly bound to organic matter (F4), Pb bound to the sulphide phase (F5). In each fraction, the concentration of Pb was determined by ICP-OES (Perkin Elmer Optima 4300 DV).



Figure 1 – Location of San Simón Bay in Ría de Vigo (NW, Spain) and position of core removal (red point).

### RESULTS

Total Pb content varied between 70.06 and 14.16 mg kg<sup>-1</sup>, being higher in the surface and decreasing with depth.

Figure 2 shows the proportion of the different fractions of Pb. The Pb present in ion-exchange form and bound to carbonate (F1) represents the mayor fraction –between 35-42% of the total–. The highest percentages of Pb found in this fraction reflected a high chemical mobility of Pb, facilitating their access to water systems.

Pb bound to the sulphide phase (F5) is the second fraction of Pb in order of abundance, assuming 35% of total Pb.

Fractions of Pb bound to organic matter (F3 plus F4) were minority in both cases, contributing to less than 12% of total Pb extracted. Moreover,

these two fractions followed an inverse behaviour because, while the weakly bound fraction (F3) increased its percentage with depth, the fraction F4 (strongly bound to the organic matter) came to disappear below 50 cm depth.

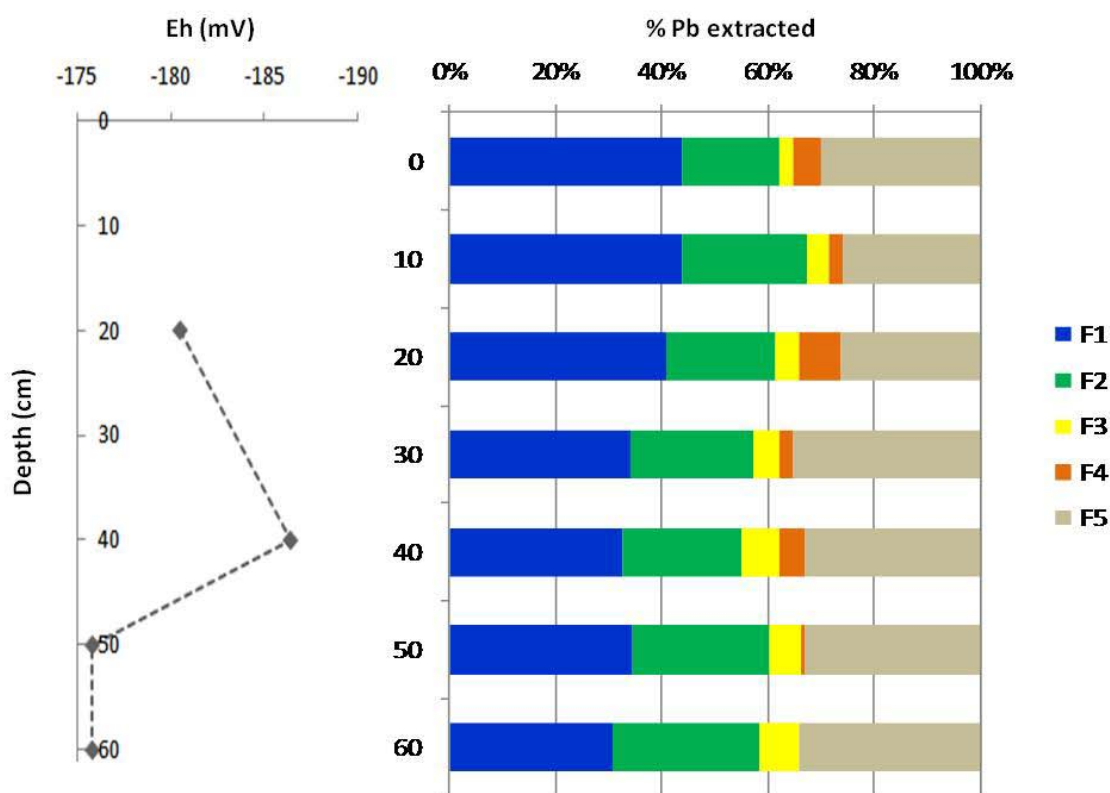


Figure 2 – Vertical distribution of Eh values in sediments of San Simon Bay and % of Pb extracted in different fractions: F1, ion exchange and bound to carbonates; F2, bound to Mn-Fe oxides; F3, weakly bound to organic matter; F4, strongly bound to organic matter; F5, bound to sulphide.

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## SPATIAL VARIABILITY OF CU IN SURFACE SEDIMENTS OF RIA DE VIGO

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**KEY WORDS:** Copper, speciation, contamination, sequential extraction.

### INTRODUCTION

The input of Cu as a contaminant in aquatic ecosystems is mainly due to anthropogenic activities. Fine-grained sediments with high organic matter contents, as the case in this study, generally act as trace metal sinks. Potentially toxic metals can be dangerous when they are in bioavailable forms. Their toxicity and bioavailability depends on different physico-chemical forms in which Cu is in the environment. In this work a fractionation of Cu is carried out in order to obtain important environmental information about the state of Cu in the Ría de Vigo.

### MATERIAL AND METHODS

Ría de Vigo, is a large submerged incised valley located at northwest Iberian Peninsula (Fig. 1) with approximately 30 km in length. At its mouth the Cíes Islands are located, which act as a barrier against storms. At the opposite place of the ría (the inner sector) the Bay of San Simón is found. The axis of the ría is oriented SW-NE and the water depth increases from less 7m in the San Simón Bay to 50 m in the south mouth of the ría.

In Ría de Vigo, the high biological productivity combined with high sedimentation rates may lead to the deposition of organic-rich mud that promote the development of anoxic conditions in the sediment, determining the speciation of metals.

Sediments were collected in two different areas of the ría. The sample C8 was collected in the inner zone, while C11 was retrieved in the outer zone. Both samples corresponded to 10 cm of the sediment surface.

Cu fractionation was performed following a sequential extraction according to Campanella et al. (1995). The extraction consists of five steps including: Cu present in ion exchange form and bound to the carbonate (F1), Cu present in the reductive phase bound to manganese-iron oxides (F2), Cu weakly bound to organic matter (F3), Cu strongly bound to organic matter (F4), and Cu bound to the sulphide phase (F5). In each fraction, the concentration of Cu was determined by ICP-OES (Perkin Elmer Optima 4300 DV).



Figure 1 – Location of Ría de Vigo (NW, Spain) and position of sampling points.

### RESULTS

Total Cu contents were similar the inner (C8) and the outer part (C11) of the Ría de Vigo ( $24.7 \text{ mg kg}^{-1}$  and  $22 \text{ mg kg}^{-1}$ , respectively). However, differences in speciation of Cu were observed between surface sediments of both zones (Fig.2).

F1 fraction, one of the most dangerous from an environmental point of view, is the most abundant in C8 ( $1.6 \text{ mg kg}^{-1}$ ) than in C11 ( $0.24 \text{ mg kg}^{-1}$ ), indicating greater mobility and toxicity of Cu in the inner zone of the Ría.

Together with F1, the fractions F3 and F4 (representing Cu bound to organic matter) were most abundant in San Simón Bay, agreeing with higher organic matter contents (TOC values of 4.6 % on average in C8 and 3.2 % in C11). In this inner zone, F4 was the major fraction for Cu ( $10.85 \text{ mg kg}^{-1}$ ).

Instead, in the outer zone, the fractions of Cu present in the reductive phase bound to manganese-iron oxides (F2) and Cu bound to the sulphide phase (F5) were more abundant. Here the F5 fraction is predominant and accounts for 46% of Cu total in this area ( $10.03 \text{ mg kg}^{-1}$ ).

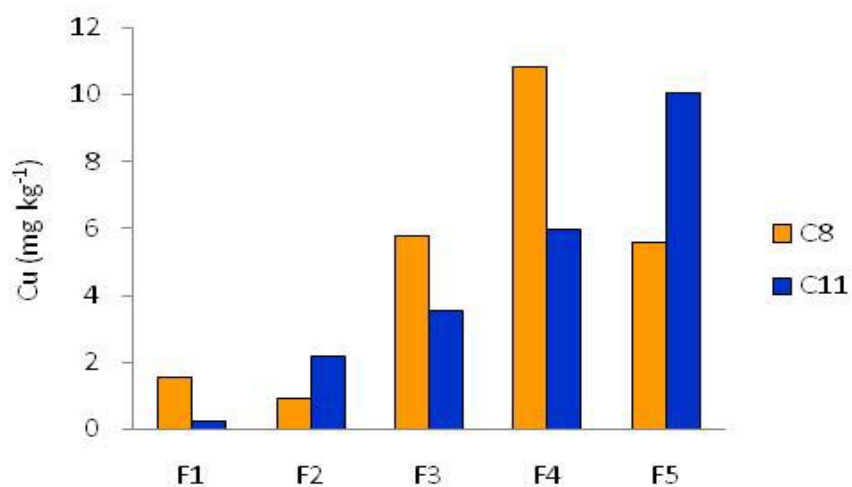


Figure 2 – Content of Cu in sediments of Ría de Vigo, extracted according to Campanella et al. (1995) method. F1, ion exchange and bound to carbonates; F2, bound to Mn-Fe oxides; F3, weakly bound to organic matter; F4, strongly bound to organic matter; F5, bound to sulphide.

## REFERENCES

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## Geochemical characterization, isotopic approach and environmental risk assessment in the DomizioFlegreo and Agro Aversano area (Campania region).

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**KEY WORDS:** *Domizio Flegreo Littoral, Agro Aversano, Environmental geochemistry, Heavy metals, Lead isotopic analysis*

### Introduction

The LIFE11 ENV/IT/000275 project has the aim to define an operative protocol for agriculture-based bioremediation of contaminated agricultural soils in the “Litorale Domizio-Agro Aversano” NIPS (National Interest Protection Site) and to identify geochemical indicators and eco-toxicological biomarkers to monitoring environmental quality. Within such project a comprehensive geochemical environmental study has been carried out focused on topsoil, groundwater, vegetable (corn) and human hair samples since former studies (Lima et al. 2012, Grezzi et al. 2011, Bove et al. 2011) pointed out the occurrence of an heavy metal pollution accross this area. Lead isotopic analysis on different matrices have been carried out to discriminate among the contamination sources of Pb and to establish their geogenic and/or anthropogenic nature (Ayuso et al. 2008).

In particular, our study concentrated on specific site affected by different pollution types: Teverola (Fondo Comunale), Trentola-Ducenta (Fondo Bove), Giugliano (Fondo Zaccaria), Castelvoturno (Soglitelle- Laghetti).

### Study area

The Domizio Flegreo Littoral and Agro Aversano area (Fig. 1) covers 1287 Km<sup>2</sup> and includes 90 municipalities. Nowadays, the total population is about 1.300.000.

Morphologically, it includes part of Campania Plain, being surrounded by the Mesozoic limestones of the Southern Apennines (N and E), the Roccamonfina volcano (N), the Somma-Vesuvius volcano (SE), the Phlegrean Fields volcanic area (SW) and the Tyrrhenian Sea (S and W).

Across the Litorale Domizio-Agro Aversano area, agriculture (tobacco, potatoes, corn) represents one of the most important economic activities.

Moreover, many industries are also present such as a production branch of FIAT, a worldwide famous automotive industry, and the Montefibre plant, producing polyester fibers, within the administrative boundaries of the Acerra municipality where also an urban waste treatment incinerator, with the capacity of 750,000 tons, operates since 2009.

In this territory, unfortunately, illegal waste disposal practices are also quite diffuse.



Figure 1 – The Litorale Domizio- Agro Aversano area

Epidemiological studies have demonstrated that in within the Acerra, Marigliano and Nola municipality territories the cancer mortality rate is higher than the regional standard and it could depend on the environmental degradation of the area. (Senior e Mazza, 2004).

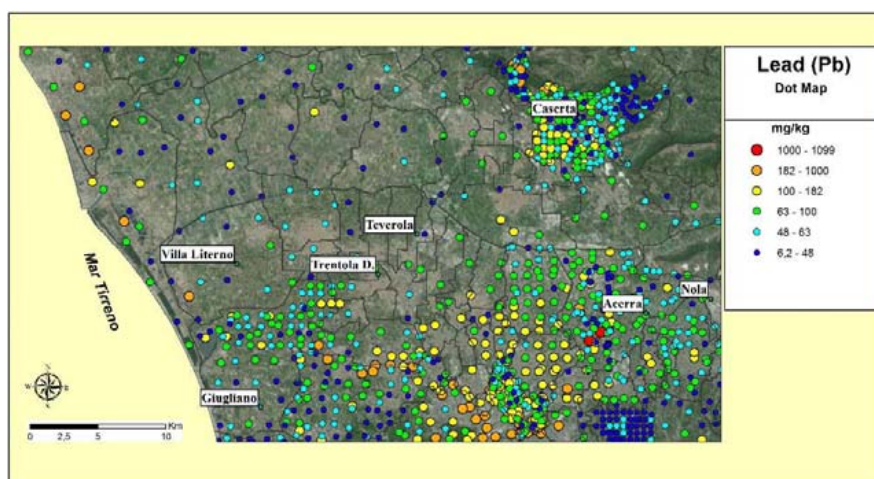


Figure 2– Pb geochemical dot map

## Material and methods

To achieve the study objectives 1064 topsoil, 27 groundwater, 24 hair and 13 corn samples have been collected across the study area (Figure 2).

For all samples the concentration of 53 elements have been determined at ACME Analytical Laboratories (Vancouver, Canada).

Samples have been analysed by inductively coupled-plasma-mass spectrometry (ICP-MS) and atomic emissions spectrometry (ICP-ES) technique, after aqua regia digestion.

Attention has been especially paid to 15 potentially toxic elements (As, Be, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sb, Se, Sn, Tl, V and Zn) for which the Italian Environmental Law (D. Lgs 152/06) establishes two trigger and action limits in soil, one for residential and recreational land use and one for industrial/commercial land use.

All the data have been statistically treated and dot, interpolated and risk maps have been produced by means of the GeoDAS software (Cheng et al., 2001; Lima et al., 2003). After generating C-A (concentration-area) plots, breaks of slope along the plot have been along the C-A plot to discriminate on the map groups of pixels characterized by a common behaviour in the spatial distribution of elemental concentrations.

Upon this step, the S-A plot (Separation Analysis) method was also used in order to separate the background values from anomalies (Cheng, 2001; Cheng et al., 1994).

Isotopic analyses have been carried out at the Radiogenic Isotope Laboratory of U.S. Geological Survey (Reston, VA, USA), using HR-ICP-MS [Thermo Scientific Element2] and the technique has allowed to discriminate geogenic vs. anthropogenic sources for Pb in soil. Of particular interest is that the human hair Pb isotopic compositions reflect quite well the anthropogenic contamination defined by aerosol and gasoline Pb isotopic ratios.

## ACKNOWLEDGEMENTS

This study is part of the action B1 of LIFE+ project LIFE11/ENV/IT/275 — ECOREMED: Implementation of eco-compatible protocols for agricultural soil remediation in Litorale Domizio-Agro Aversano NIPS launched in 2012 (Coordinator Prof. M. Fagnano).

This study is part of PhD program (XXIX Cycle) of University of Naples Federico II, Department of Earth, Environmental and Resources Science.

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# A KINETIC STUDY OF PESTICIDE SORPTION ON VARIOUS MEDITERRANEAN SOILS

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**KEY WORDS:** soil contamination, non-ionic pesticides, sorption kinetics, mathematical models.

## INTRODUCTION

Adsorption of pesticides on soils is a time-dependent process governed by the difference between the amount currently adsorbed and the amount that would be adsorbed if the system was in equilibrium. Therefore, kinetic studies are needed to evaluate the equilibrium time and the mechanisms involved. In this work we dealt with kinetic aspects of the adsorption of pesticides with contrasting properties on agricultural soils.

## MATERIALS AND METHODS

Pesticides and soils: thiacloprid (THC), dimethenamid (DIM) and fenarimol (FEN) (Figure 1). Some soil properties are shown in Table 1.

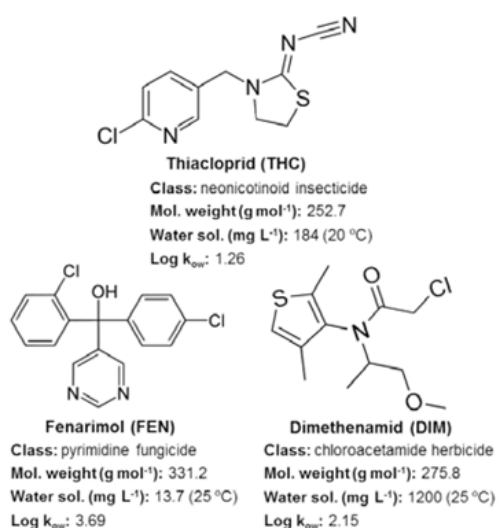


Figure 1 – Physicochemical properties of pesticides

Kinetic experiments: triplicate samples using the batch equilibration method. Five g of sieved soil (2 mm) was mixed with 20 mL of a solution containing the pesticides at 2 μg mL<sup>-1</sup>. The samples were shaken at 20 °C up to 24 h. Pesticide concentration in the supernatants (*C<sub>e</sub>*) was determined by HPLC-DAD. The adsorbed amount (*X*) was calculated by difference between

the initial and equilibrium concentrations in solution.

Table 1 – Physicochemical properties of soils

SOIL	% SAND	% SILT	% CLAY	% OC
SV	31	58	11	1.1
RM1	10	39	51	0.6
RM3	26	41	33	0.9

### Kinetic modelling:

- Pseudo Second Order (PSO) Model:

$$t/X_t = (1/K_{\text{PSO}}X_{\text{max}}^2) + (t/X_{\text{max}})$$

*K<sub>PSO</sub>* (g μg<sup>-1</sup> min<sup>-1</sup>): PSO kinetic rate constant  
*X<sub>max</sub>*, *X<sub>t</sub>* (μg g<sup>-1</sup>): adsorbed concentration at equilibrium and at time *t*

- Elovich Equation:

$$X_t = \ln(\alpha\beta)/\beta + \ln(t)/\beta$$

*α* (μg g<sup>-1</sup> min<sup>-1</sup>): initial adsorption rate  
*β* (g μg<sup>-1</sup>): extent of surface coverage

- Intraparticle Diffusion (IPD) Model:

$$X_t = C + K_{\text{int}}t^{1/2}$$

*C* (μg g<sup>-1</sup>): constant related to the extent of the boundary layer thickness

*K<sub>int</sub>* (μg g<sup>-1</sup> min<sup>1/2</sup>): intraparticle diffusion rate constant

In this model the initial adsorption factor *R<sub>i</sub>* (dimensionless) is defined as:

$$R_i = (K_{\text{int}}t_{\text{ref}}^{1/2} / X_{\text{ref}}) = 1 - (C / X_{\text{ref}})$$

$$X_{\text{ref}} = K_{\text{int}}t_{\text{ref}}^{1/2} + C$$

*t<sub>ref</sub>* (min): longest time in adsorption process

*X<sub>ref</sub>* (μg g<sup>-1</sup>): adsorbed amount at *t* = *t<sub>ref</sub>*

When *R<sub>i</sub>* approaches 1, the contribution of fast initial adsorption is negligible and adsorption is entirely controlled by IPD (Wu et al., 2009).

## RESULTS AND DISCUSSION

Adsorption equilibrium was achieved within 24 h for all the pesticides (Figure 2). The adsorption

capacity of the soils was ranged according to pesticide's hydrophobicity. The shape of the curves indicates that the dominance of either surface or internal phenomena is dependent on pesticide properties.

PSO was the model that best described experimental data (Table 2). The predicted  $X_{max}$  values agreed with the experimental ones, with the lowest differences (0-3.5%). According to  $K_{PSO}$  values, adsorption rate was ranged as DIM > FEN > THC. DIM adsorption on SV was slower as compared with RM1 and RM3. For FEN, adsorption on RM3 was faster, followed by SV and RM1.

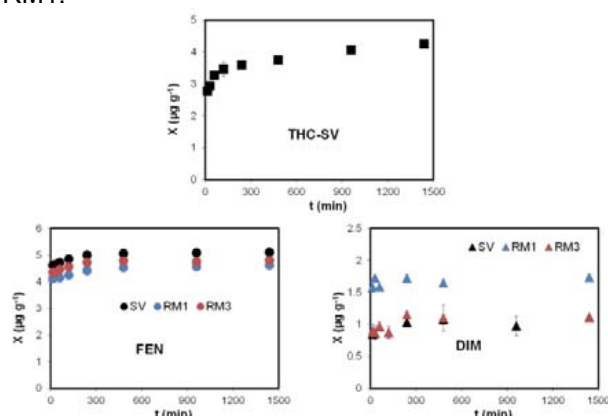


Figure 2 – Kinetic curves for pesticide adsorption on soils

Elovich equation was suitable to describe THC, and FEN adsorption, as well as that of DIM in SV and RM3 (Table 2). The poorer fitting for DIM can be due to its high water solubility, since this equation neglects the effect of simultaneously occurring desorption (Plazinski et al., 2009). In SV the  $\beta$  values indicated a higher number of active sites available for DIM, followed by FEN and THC, which disagrees with pesticide affinity for soil. The initial adsorption rate ( $\alpha$ ) was much higher for FEN, showing a high affinity for soil colloids. Soil

OC seems to be the main factor responsible for FEN adsorption, with  $\alpha$  two orders of magnitude lower for RM1 soil, with less OC content.

IPD model was successfully applied, except for DIM, for which the model only fitted poorly SV data (Table 2). DIM and FEN exhibited the lowest  $K_{int}$ , followed by THC. Soil texture is not a determinant factor, since no great differences were observed for FEN in the three soils. In all the cases C was positive, indicating that adsorption is not exclusively controlled by IPD. The values of  $R_i$ , between 0.11 and 0.34, indicate strong contribution of initial adsorption (Wu et al., 2009) in accordance with kinetic curves (Figure 2). IPD is more relevant for THC (higher  $R_i$ ), followed by DIM and FEN, where adsorption takes place almost completely in the initial rapid stage ( $\approx 90\%$ ).

## ACKNOWLEDGEMENTS

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Table 2 – Kinetic parameters predicted from the fitting of pesticide adsorption to the different models

Soil	Pest	†Exp. $X_{max}$	PSO			Elovich			IPD			
			$X_{max}$	$K (x10^3)$	$R^2$	$\alpha$	$\beta$	$R^2$	$K_{int}$	C	$R_i$	$R^2$
SV	THC	4.24	4.25	8.39	0.998**	157	3.2	0.987**	0.04	2.85	0.34	0.923**
	DIM	1.11	1.08	57.7	0.994**	58369	19.7	0.693*	0.006	0.86	0.22	0.623*
	FEN	5.10	5.11	43.9	1**	$2.3 \cdot 10^{14}$	8.2	0.956**	0.015	4.64	0.11	0.818**
RM1	DIM	1.73	1.73	100.3	1**	$3.3 \cdot 10^{30}$	47.4	0.268#				
	FEN	4.61	4.62	29.98	1**	$2.6 \cdot 10^{12}$	8.2	0.941**	0.016	4.08	0.13	0.906**
RM3	DIM	1.15	1.11	106.3	0.999**	8310	16.8	0.617*				
	FEN	4.80	4.80	50.5	1**	$2.5 \cdot 10^{14}$	8.8	0.925**	0.014	4.36	0.11	0.773**

Parameter units defined in Materials and Methods

† Experimental maximum adsorbed amount; \* $P < 0.05$ ; \*\* $P < 0.01$ ; # not significant ( $P > 0.05$ )

# PESTICIDE SORPTION/DESORPTION ON MEDITERRANEAN SOILS MODIFIED BY SOLUTION COMPOSITION

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**KEY WORDS:** pesticides, adsorption-desorption, agricultural soils, wastewater, sewage sludge

## OBJECTIVES

Irrigation with low-quality waters can modify the adsorption-desorption behaviour of pesticides to soil, thus affecting the potential risk of surface- and groundwater contamination. We assessed the impact of urban wastewater (WW) and dissolved organic carbon (DOC) solutions (30, 90 and 300 mg L<sup>-1</sup> DOC) from sewage sludge in the adsorption-desorption behaviour of two pesticides on agricultural soils.

## EXPERIMENTAL SETUP

Adsorption-desorption isotherms were performed by the batch method in triplicate. Five g of sieved soil (2 mm) was mixed with 20 mL of a solution containing the pesticides and shaken for 24 h at 20 °C. After centrifugation at 3000 rpm, an aliquot of the supernatant was filtered (0.45 µm PVDF filters) and equilibrium concentration of pesticides (C<sub>e</sub>) was determined by HPLC-DAD. The adsorbed amount (X) was calculated as the difference between the initial and equilibrium concentrations.

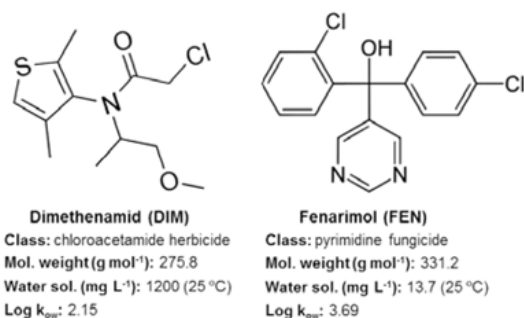


Figure 1 – Pesticide structure and some physicochemical properties

Adsorption was studied in the concentration range 0.5–5 µg mL<sup>-1</sup>, and desorption at the highest concentration of the adsorption isotherm. Four

desorption steps were completed. Experimental points were fitted to the Freundlich model:  $X=K \cdot C_e^{1/n}$ . Physicochemical properties of pesticides and soils are shown in Figure 1 and Table 1, respectively.

Table 1 – Physicochemical properties of soils

SOIL	% SAND	% SILT	% CLAY	% OC
SV	31	58	11	1.1
RM1	10	39	51	0.6
RM3	26	41	33	0.9

## RESULTS AND DISCUSSION

Adsorption-desorption isotherms (Figure 2) were well-fitted to the Freundlich model ( $R^2 > 0.90$  for adsorption;  $R^2 > 0.72$  for desorption). Freundlich parameters are listed in Table 2. FEN and DIM were moderately and weakly adsorbed in soils respectively, according to their physicochemical properties. While FEN isotherms were close to linearity (C-type) ( $1/n \geq 0.90$ ), those of DIM were L-type with  $1/n \leq 0.83$ . FEN adsorption was ranged according to the OC content of soil (SV > RM3 > RM1), in agreement with other works (Oliver et al. 2003; Rodríguez-Liébana et al. 2013). In the case of DIM the mineral fraction of soil seems to acquire relevance (Archangelo et al. 2004). WW did not influence pesticide adsorption, whereas DOC solutions increased it, linearly for FEN ( $R^2 \geq 0.87$ ;  $P \leq 0.05$ ) for SV and RM3 and with no statistical relationship for DIM.

Desorption isotherms of both compounds showed varying degree of hysteresis indicating that adsorption was only partially reversible. DIM desorption was more hysteretic (lower H) than that of FEN. In contrast, FEN desorbed less than DIM reinforcing the importance of pesticide properties on their affinity for soil particles. Although H values for FEN were lower with DOC 30 and DOC 90 solutions, it did not considerably affect desorbed percentages (D). On the other hand,  $D_{DIM}$  was higher with the solutions that exhibited less hysteresis, that is WW and DOC 300.

Table 2 – Freundlich adsorption parameters ( $K_f$  and  $1/n$ ), hysteresis coefficient ( $H$ ) and total desorbed amount ( $D$ ) of pesticides in soils

Soil		$K_f$	$1/n$	$H^a$	$D^b$	$K_f$	$1/n$	$H$	$D$
		DIM					FEN		
SV	MQ	0.66 ± 0.03	0.83 ± 0.04	0.33	48 ± 5	8.07 ± 0.28	0.93 ± 0.02	0.55	40 ± 1
	WW	0.58 ± 0.03	0.77 ± 0.04	0.56	64 ± 7	8.46 ± 0.18	0.96 ± 0.01	0.55	39 ± 1
	DOC 30	0.74 ± 0.05	0.91 ± 0.06	0.24	44 ± 4	8.25 ± 0.28	0.98 ± 0.03	0.42	37 ± 3
	DOC 90	0.76 ± 0.02	0.75 ± 0.02	0.33	48 ± 3	8.27 ± 0.11	0.93 ± 0.01	0.48	37 ± 2
	DOC 300	0.77 ± 0.02	0.72 ± 0.02	0.63	68 ± 2	8.85 ± 0.09	0.93 ± 0.01	0.56	38 ± 0
RM1	MQ	1.14 ± 0.04	0.83 ± 0.03	0.47	60 ± 8	6.00 ± 0.09	0.90 ± 0.01	0.63	48 ± 2
	WW	1.04 ± 0.04	0.86 ± 0.03	0.71	74 ± 0	6.21 ± 0.17	0.93 ± 0.02	0.61	47 ± 0
	DOC 30	1.20 ± 0.06	0.93 ± 0.04	0.47	62 ± 2	6.28 ± 0.24	0.94 ± 0.03	0.45	42 ± 1
	DOC 90	1.20 ± 0.07	0.94 ± 0.05	0.44	61 ± 2	6.61 ± 0.18	0.94 ± 0.02	0.47	42 ± 2
	DOC 300	1.19 ± 0.03	0.83 ± 0.02	0.76	75 ± 3	6.41 ± 0.07	0.93 ± 0.01	0.57	45 ± 0
RM3	MQ	0.60 ± 0.02	0.80 ± 0.03	0.38	51 ± 16	6.78 ± 0.14	0.93 ± 0.02	0.75	49 ± 1
	WW	0.55 ± 0.06	0.82 ± 0.09	0.61	70 ± 2	7.28 ± 0.10	0.94 ± 0.01	0.73	48 ± 1
	DOC 30	0.66 ± 0.06	0.94 ± 0.07	0.30	50 ± 1	7.21 ± 0.24	0.98 ± 0.03	0.59	44 ± 1
	DOC 90	0.77 ± 0.04	0.74 ± 0.04	0.43	59 ± 3	7.16 ± 0.13	0.93 ± 0.01	0.59	45 ± 2
	DOC 300	0.82 ± 0.04	0.70 ± 0.04	0.56	64 ± 2	7.75 ± 0.36	0.95 ± 0.03	0.68	45 ± 0

<sup>a</sup> $H = 1/n_d / 1/n_a$

<sup>b</sup> $D (\%) = (X_0 - X_f) * 100 / X_0$ .  $X_0$  initial adsorbed concentration;  $X_f$  adsorbed concentration after 4 desorption steps

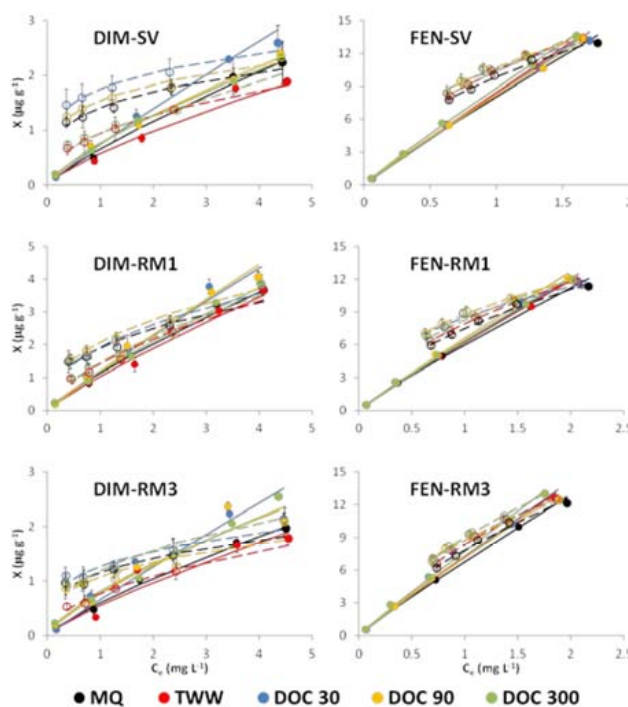


Figure 2 – Adsorption (filled symbols and continuous lines) and desorption isotherms (unfilled symbols and dashed lines)

## CONCLUSIONS

Soil organic matter and DOC are the main responsible for FEN adsorption, while for DIM the role of mineral fractions cannot be excluded. According to the desorption parameters ( $H$  and  $D$ ) FEN desorption was practically not affected by the solutions. Adsorption of DIM with WW and DOC

300 solutions was more reversible (higher  $H$ ) showing the highest desorption percentages. Therefore, we may conclude that the composition of the irrigation solution may modify the potential risk of groundwater contamination for non-ionic pesticides of intermediate hydrophobicity, such as DIM, which is weakly adsorbed on soil.

## ACKNOWLEDGEMENTS

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# EFFECT OF COMPOST AND BOTTOM ASHES ON METALS AND As RELEASE FROM CONTAMINATED SOILS: A LEACHING COLUMN STUDY

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**KEY WORDS:** Remediation, leaching column experiments, contaminated soil, amendments

Table 1 – Characteristics of soils and amendments.

	P1	P2	SVC	BA
pH	2.5	2.4	7.3	13.4
EC (dS m <sup>-1</sup> )	1.0	2.4	11.4	39.4
OC (g kg <sup>-1</sup> )	15.6	< d.l	194	15.9
Al (g kg <sup>-1</sup> )	26.9	29.4	24.3	17.3
Fe (g kg <sup>-1</sup> )	229	87.3	20.4	7.98
Mn (mg kg <sup>-1</sup> )	425	56	282	477
As (mg kg <sup>-1</sup> )	3952	1018	5.0	< d.l.
Cu (mg kg <sup>-1</sup> )	606	208	161	118
Pb (mg kg <sup>-1</sup> )	3575	2177	60	6.7
Zn (mg kg <sup>-1</sup> )	111	94	517	48.3
NO <sub>3</sub> (mg kg <sup>-1</sup> )	4.7	1.7	217	174
NH <sub>4</sub> (mg kg <sup>-1</sup> )	0.9	0.9	4094	< d.l
PO <sub>4</sub> (mg kg <sup>-1</sup> )	129	5.1	777	2153

EC: electrical conductivity; OC: organic carbon; d.l.: detection limit

## INTRODUCTION

Contamination of water bodies and soils due to mining activities has been of great concern over the last decades. Understanding the potentially toxic element release into the water is crucial in the prediction, prevention and remediation of environmental impacts. These concerns have promoted the emergence of cost-effective alternatives for soil remediation. Among these technologies, in situ immobilization of hazardous elements by amendment incorporation has received a growing interest. Moreover, some amendments are inexpensive and readily available in large quantities because they derive from bio-products or industrial by-products.

To estimate the amendment effects on potentially toxic element release, several studies have been conducted using different approaches, such as column experiments (Salinas-Villafane et al., 2012). This work reports the results of a series of leaching column experiments designed to investigate the potential of two by-products (compost of urban sewage sludge and bottom ashes from biomass combustion) as a remediation treatment for multielement-contaminated soils.

## MATERIALS AND METHODS

Two soil samples (P1 and P2) were randomly collected from different points of a tailing dump of Riotinto mining district (province of Huelva, SW Spain) located in the Iberian Pyrite Belt.

The compost (SVC) was supplied by a local company and produced by composting urban sewage sludge and agricultural by-products (50:50).

The bottom ash (BA) is a by-product of biomass combustion provided by a local biomass power plant which uses as fuel a mixture of olive pomace and energetic crops (40:60).

The materials were air dried, sieved (< 2-mm) and characterized (Table 1).

Both soil samples were amended with two mixtures: mixture 1 (M1) was composed by 6.8% SVC + 0.5% BA; mixture 2 (M2) by 6.8% SVC + 3.1% BA. Amended and unamended soils (250 g) were incubated over 30 days at 50 % field capacity at temperatures of 30 °C/15 °C day/night. At the end of the incubation, soil was packed into columns (135 mm high and 27 mm inner diameter) to a height of 100 mm. Columns were daily irrigated with 10 mL of MilliQ water up to 100 mL, equivalent to a third of the annual precipitation in the area. All treatments were performed in triplicate. In the leachates, concentrations of Al, Fe, Mn, Cu, Pb, Zn and As were measured by ICP-OES. pH, electrical conductivity and the concentrations of NO<sub>3</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup> and NH<sub>4</sub><sup>+</sup> were also determined by standard methods. Differences among treatments were analysed by ANOVA.

## RESULTS AND DISCUSSION

In unamended soils, concentration of Al, Fe, Mn, Cu and Zn were extremely high and, together with the concentration of Pb (0.10 mg L<sup>-1</sup> and 0.22 mg L<sup>-1</sup> in P1 and P2 respectively), far exceeded the levels established for human water consumption (Figure 1). In P2, leaching of Al, Fe and Zn was greater than in P1 (Figure 1), which agrees with more acid pH and lower content of organic matter in P2 (Table 1). Moreover, very low pH and high EC were observed in the drainage of both unamended soils, especially in P2 (Table 2).

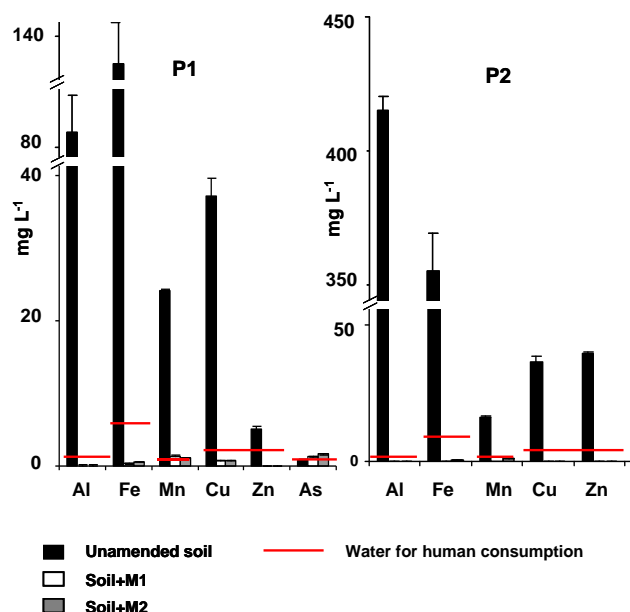


Figure 1 – Metal and As concentration in the leachates from unamended or amended soils (P1 and P2).

The application of M1 and M2 drastically decreased metal leaching from both soils (Figure 1), including Pb which was below the detection limit of the method ( $0.01 \text{ mg L}^{-1}$ ). Only Mn remained slightly higher than the levels established for human water consumption. No significant differences ( $p > 0.05$ ) were observed between application of M1 and M2, even among the different soils. With the amendments, metals were immobilized in the solid phase primarily due to pH increases (Table 2) as well as organic matter contribution to metal adsorption.

Table 2 – Chemical characteristics of the leachates.

	pH	EC ( $\text{dS m}^{-1}$ )	$\text{NO}_3$ ( $\text{mg kg}^{-1}$ )	$\text{NH}_4$ ( $\text{mg kg}^{-1}$ )
<b>P1</b>	$2.8 \pm 0.1^a$	$2.7 \pm 0.1^a$	$5 \pm 4^a$	$0.1 \pm 0.05^a$
<b>P1+M1</b>	$7.1 \pm 0.1^b$	$6.7 \pm 0.1^b$	$34 \pm 2^b$	$527 \pm 61^b$
<b>P1+M2</b>	$7.7 \pm 0.1^c$	$11 \pm 0.3^c$	$52 \pm 1^c$	$342 \pm 68^b$
<b>P2</b>	$2.4 \pm 0.1^d$	$7.2 \pm 0.1^d$	$4 \pm 5^a$	$0.1 \pm 0.04^a$
<b>P2+M1</b>	$7.1 \pm 0.1^b$	$8.9 \pm 0.4^b$	$15 \pm 1^d$	$604 \pm 82^b$
<b>P2+M2</b>	$7.6 \pm 0.1^c$	$11 \pm 0.3^c$	$70 \pm 7^e$	$312 \pm 61^b$

In the same column, values with different superscripts indicate significant differences ( $p < 0.05$ ).

Arsenic showed a different behaviour compared to metals. In P1, both mixtures significantly increased the concentration of As in the leachates (Figure 1), more for M2 than for M1. This could be due to a pH increase and to a higher  $\text{PO}_4^{3-}$  concentration after amendment application (Beesley et al., 2014), especially by BA addition (Table 1).

Finally, high concentrations of  $\text{NO}_3^-$  and  $\text{NH}_4^+$  were found in the leachates from amended soils (Table 2), which could increase the risk of eutrophication. By contrast, no risk was associated with  $\text{PO}_4^{3-}$  concentration which was below the detection limit of the method ( $0.1 \text{ mg L}^{-1}$ ).

## CONCLUSIONS

Additions of sewage sludge compost and bottom ashes have the potential to be a useful treatment for metal-contaminated soils. However, more research needs to be conducted to assess the potential risks associated with the increase of As and N concentration in the leachates.

## ACKNOWLEDGEMENTS

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# MODELLING AGROCHEMICAL PROPERTIES AND HAZARDOUS ELEMENT AVAILABILITY OF A MULTIELEMENT-CONTAMINATED SOIL AMENDED WITH WASTES

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**KEY WORDS:** Reclamation strategy, hazardous elements, Response Surface Methodology

Table 1 – Characteristics of soil and amendments.

	Soil	SVC	BA
<b>pH</b>	2.5	7.3	13.4
<b>EC</b> (dS m <sup>-1</sup> )	1.0	11.4	39.4
<b>OC</b> (g kg <sup>-1</sup> )	15.6	194	15.9
<b>Al</b> (g kg <sup>-1</sup> )	26.9	24.3	17.3
<b>Fe</b> (g kg <sup>-1</sup> )	229	20.4	7.98
<b>Mn</b> (mg kg <sup>-1</sup> )	425	282	477
<b>As</b> (mg kg <sup>-1</sup> )	3952	5.0	< d.l.
<b>Cu</b> (mg kg <sup>-1</sup> )	606	161	118
<b>Pb</b> (mg kg <sup>-1</sup> )	3575	60	6.7
<b>Zn</b> (mg kg <sup>-1</sup> )	111	517	48.3

EC: electrical conductivity; OC: organic carbon; d.l.: detection limit

## INTRODUCTION

In mine dumps the survival and growth of plants are mainly limited by extremely low pH, high electrical conductivity (EC) and hazardous element toxicity, among others. Application of amendments contributes to a sustainable management strategy of contaminated mine sites. However, quantitative prediction of chemical properties and hazardous element availability is a prerequisite for proper assessment of potential environmental impacts from the utilization of different materials as amendments. In this sense, mathematical models can provide insights into the system behaviour, thus helping to assess (i) the risk of high pollutant loads and (ii) the effectiveness of potential remediation strategies. From a practical viewpoint, the Response Surface Methodology (RSM) is an empirical modeling tool useful for analyzing and optimizing the response of multivariate systems (Myers and Montgomery 2002). This study was aimed to (1) modeling, using RSM, how application of two amendments affected agrochemical properties and hazardous element availability of a multielemental contaminated soil and (2) predicting the most adequate mixture for control of environmental risk and growth of several energetic crops.

## MATERIALS AND METHODS

The soil (25 kg) was collected in a tailing dump of Riotinto mining district (province of Huelva, SW Spain) located in the Iberian Pyrite Belt.

The compost (SVC) was supplied by a local company and produced by composting urban sewage sludge and agricultural by-products (50:50).

The bottom ash (BA) is a by-product of biomass combustion provided by a local biomass power plant which uses as fuel a mixture of olive pomace and energetic crops (40:60).

The three components were air dried, sieved (< 2-mm) and characterized (Table 1).

Amendment application was carried out following a D-optimal design in which the doses of each waste varied between 0 and 30% and the sum of both residues was 30% of the final mixture. The design consisted of 15 mixtures which were incubated (100 g) in the laboratory during 30 days at 50% field capacity and temperatures of 30 °C/15 °C day/night. At the end of the incubation, pH, EC, and available (extractable with CaCl<sub>2</sub> 0.01 M) As, Al, Mn, Fe, Cu, Pb and Zn were measured. Data were processed with Design-Expert 7.1.3 statistical software; the responses were fitted to second-order polynomial models and surface contour plots were obtained.

Once the models were generated for each variable studied, an optimal mixture for a reclamation strategy was determined according to the Derringer desirability function (Sevilla-Perea et al., 2013). This allowed locating an optimal region considering simultaneously optimal pH and EC values for crop growth and minimal hazardous element availability. Then, the optimal mixture was incubated, and pH, EC, and available hazardous elements were measured. In addition, its effectiveness for some energetic crop growth (*Hordeum vulgare*, *Cynara cardunculus* and *Brassica carinata*) was evaluated by germination and root elongation tests. For this proposal, the optimal mixture was extracted with MilliQ water (1:10 w:v) and the supernatant used for the bioassays. All the assays were performed in triplicate and differences were analyzed by ANOVA.

## RESULTS AND DISCUSSION

The values of pH, EC and available As, Al, Mn, Fe, Cu, Pb and Zn in soil after the incubation experiments were fitted to a quadratic polynomial equation by partial least squares. As metals behavior was very similar, they were jointly assessed. In all cases, more than 95% of the total variance was explained by the fitted models ( $R^2 \geq 0.95$ ), with no significant lack of fit ( $p > 0.05$ ). The  $Q^2 > 0.7$  pointed to an excellent prediction ability. Significant regression coefficients (not shown) indicate that both amendments significantly increase pH and EC values, but higher effect corresponds to BA (Figure 1 a and b).

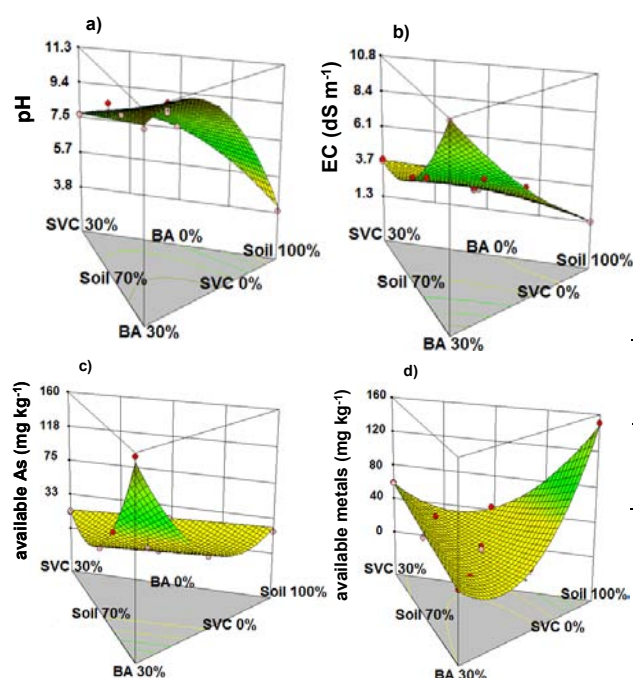


Figure 1 – Surface response plots showing the effect of compost (SVC) and bottom ash (BA) on soil properties: a) pH; b) electrical conductivity; c) As availability and d) metals (Al+Fe+Mn+Cu+Pb+Zn) availability.

In relation to hazardous elements, different behaviour of As was observed with respect to all metals (Figure 1 c and d) probably because As is present in soil in anionic or neutral form while the metals are present in cationic form. The effect of SVC on As availability was negligible compared to the addition of BA, which sharply increased the concentration of easily available As. By contrast, both amendments significantly contribute to reducing the concentration of metals in the soil solution.

The models can be optimized for any combination of one or more goals. In this work, models were used to predict the optimal

combination of amendments for crop growth considering simultaneously adequate pH (7.5) and EC ( $2.4 \text{ dS m}^{-1}$ ) and minimal hazardous element availability. According to these assumptions, the model-optimized result indicated that these optimal conditions would be reached adding to the soil 6.8% of SVC and 3.1% of BA.

After the optimal mixture incubation, its pH (7.7) and EC ( $2.72 \text{ dS m}^{-1}$ ) were in agreement with the values predicted by the model ( $7.5 \pm 0.19$  and  $2.79 \pm 0.07$  respectively). In addition available As ( $8.92 \text{ mg kg}^{-1}$ ) was not significantly different from non-amended soil ( $8.29 \text{ mg kg}^{-1}$ ) indicating that BA application was conducted in a sustainable way. Moreover, the sum of available metals ( $31.59 \text{ mg kg}^{-1}$ ) was significantly lower than in non-amended soil ( $151.1 \text{ mg kg}^{-1}$ ), therefore the toxicity of the substrate decreased.

Finally, the optimal mixture significantly increased the germination and root length of all energetic crops (Table 2) confirming the lower toxicity of the substrate.

Table 2 – Germination (G) and root length (R) of energetic crops in MilliQ water (control) and water extracts of non-amended soil (soil) and soil amended with the optimal mixture (mixture).

	<i>H. vulgare</i>		<i>C. cardunculus</i>		<i>B. carinata</i>	
	G (%)	R (mm)	G (%)	R (mm)	G (%)	R (mm)
Control	96 <sup>a</sup>	71 <sup>a</sup>	95 <sup>a</sup>	37 <sup>a</sup>	96 <sup>a</sup>	46 <sup>a</sup>
Soil	21 <sup>b</sup>	2 <sup>b</sup>	88 <sup>b</sup>	1 <sup>c</sup>	13 <sup>b</sup>	1 <sup>c</sup>
Mixture	97 <sup>a</sup>	64 <sup>a</sup>	90 <sup>a</sup>	29 <sup>b</sup>	99 <sup>a</sup>	27 <sup>b</sup>

In the same column, values with different superscripts indicate significant differences ( $p < 0.05$ ).

## CONCLUSIONS

This methodology can be used for reclamation approaches of contaminated soils to predict the most adequate mixtures for vegetation growth and environmental risk control.

## ACKNOWLEDGEMENTS

Authors wish to acknowledge funding from the Ramon Areces Foundation through the project CIVP16A1840 (<http://www.fundacionareces.es>). A. Sevilla-Perea thanks Junta de Andalucía for a postdoctoral fellowship.

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## EROSION MODELING BY WEPP IN PLOTS TREATED WITH SOLAR-DRIED CITRUS PEEL

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**KEY WORDS:** soil conservation, citrus peel, runoff, WEPP model.

### INTRODUCTION

Steep and bare slopes of large areas of southern Italy are often subject to intense runoff and erosion after heavy and flash rainstorms. In these contexts, the hydrologic response of soils could be improved by enhancing infiltration through addition of organic matter. This is the case of marginal zones close to agro-industries, where wastewater and by-products (such as citrus peel) could be distributed on soils at low cost. Citrus peel, because of its high content of organic matter (OM), could be used as a soil organic conditioner: this use makes easy its disposal and allows also its valorisation in order to reduce soil erosion rates in Mediterranean environment (Bombino *et al.* 2010). The hydrological benefits of citrus peel addition to soil can be easily evaluated also by a modelling approach. As well known, during the last decades, many prediction models have been developed for prediction of hydrological variables under different environmental conditions and time/spatial scales. Among them, WEPP (Water Erosion Prediction Project), a physically-based, distributed parameters, continuous simulation (Nearing *et al.*, 1989), has been widely applied under varying climatic and geomorphologic conditions. The model simulates at event scale surface runoff and soil loss in plots, hillslopes and watersheds. This work aims at evaluating WEPP prediction capability for surface runoff and soil loss in artificial steep slopes with bare soil and treated with solar-dried orange peel in semi-arid Mediterranean conditions; furthermore, the model capability to quantify hydrological benefits of OM addition to soil is investigated.

### MATERIALS AND METHODS

WEPP model was implemented in small plots installed in the experimental farm of the University "Mediterranea" of Reggio Calabria (Southern Italy); this area is characterised by climatic conditions typical of the Mediterranean basin, with mild rainy winter and warm dry summer.

Eight plots (area of 2 m<sup>2</sup> and slope of 100%), containing an upper layer (40 cm) of agricultural

soil (59% sand, 29% silt and 12% clay with a OM content of 1.3%) and a lower layer (10 cm) of gravel, were built: four plots were treated with solar-dried orange peel (previously shredded and then incorporated in the 3-cm surface layer at a dose of 3 kg m<sup>-2</sup>) and the other were considered as control, because not subject to any treatment (Figure 1).

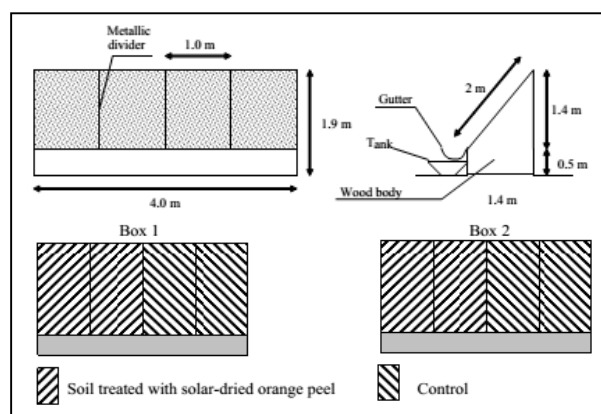


Figure 1 – Scheme of the experimental plots.

All plots were exposed to 15 natural rainfalls; as many events of runoff and soil loss were recorded. Runoff was collected in a tank and its volume measured after each event; soil loss was measured by weighing the eroded soil after oven drying (at 105 °C) the collected runoff. The measured volumes were referred to the projection of the plot surface on the horizontal plan (1.4 m<sup>2</sup>). The hydrological observations were visually compared to the corresponding predictions by WEPP. Model performance was evaluated by the coefficients of determination ( $r^2$ ) and model efficiency (E, Nash and Sutcliffe, 1970), as usually done in modelling experiences.

### RESULTS AND DISCUSSIONS

Table 1 reports the values of the observed events on control and treated soils.

In both treated and control plots runoff volumes predicted by WEPP were well correlated ( $r^2 = 0.98$ ) to the corresponding observations.

Table 1 – Values of the hydrological observations for 15 events on control (C) and treated (T) soils.

Event	Rainfall		Runoff volume (mm)		Soil loss (kg m <sup>-2</sup> )	
	Height (mm)	Mean intensity (mm h <sup>-1</sup> )				
			T	C	T	C
1	4.1	1	0.6	0.5	0	0.1
2	80	18.2	24.1	23.9	3.5	5.5
3	60	16.7	17	16.9	0.5	0.8
4	11.7	20.5	3.5	3.6	0	0.0
5	4.3	1.8	2.3	2.5	0	0
6	12.4	2.4	2.2	2.6	0	0
7	22.4	5.6	6.7	7	0.6	0.4
8	22.2	1.3	5	6.1	0.1	0.1
9	9.4	0.5	2.5	3.3	0	0
10	14.3	1.7	4	4.3	0	0
11	1.0	1.0	0.4	0.5	0	0
12	10.6	3	4.8	5	0.1	0.1
13	5.3	1.9	1.6	1.8	0	0
14	55	15.5	16.5	19.2	0.1	2.8
15	5	1.3	0.9	1.4	0	0

T = treated plot (added with citrus peel); C = control plot (without treatments).

Despite this correlation, E was equal to -4.7, showing a poor model prediction capability, also after the setup of the most sensitive input soil parameters. A strong tendency to overestimation (on the average by 195%) was noticed in both control and treated plots (Figure 2a), particularly for the largest rainfall events. This tendency was lower (+70%) for the events with intensity lower than 15 mm h<sup>-1</sup> measured in treated plots.

WEPP performance was unsatisfactory also for erosion evaluations, being predicted soil losses far from the corresponding observed values in both control and treated plots (Figure 2b); this was also confirmed by the low E (0.11).

However, WEPP model was able to catch the hydrological benefits linked to OM addition to soils; as a matter of fact, the observed reduction of soil loss between treated and control plots (on the average -78%) is very close to what simulated by the model (-75%).

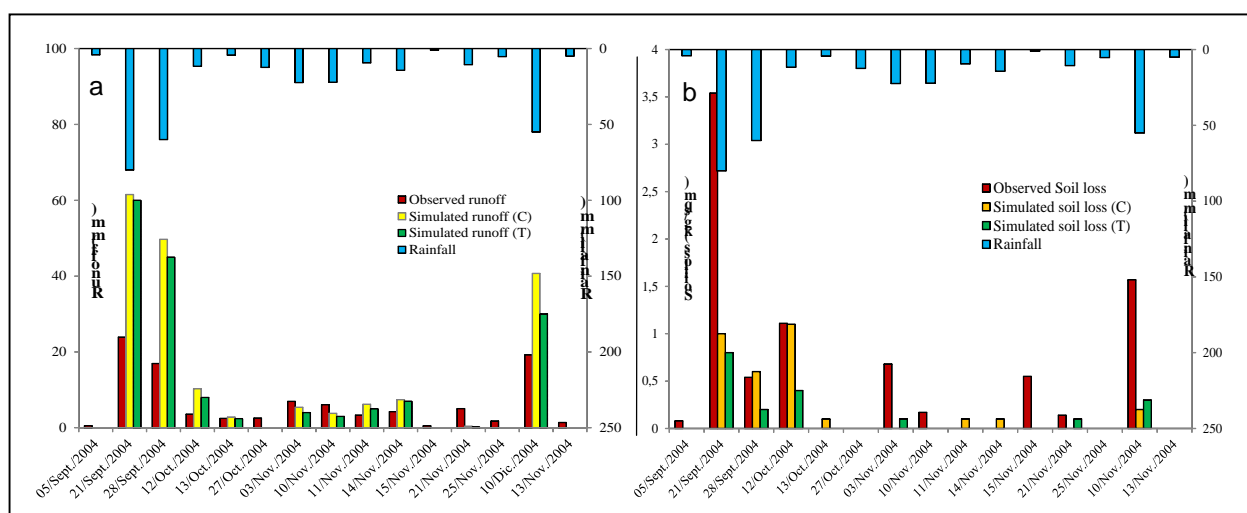


Figure 2 – Comparison of observed and predicted surface runoff (a) and soil loss (b) volumes in the experimental plots (T = treated; C = control).

## CONCLUSIONS

Typical conditions of marginal areas of Southern Italy under semi-arid Mediterranean climate was simulated by WEPP. Surface runoff volumes and soil loss produced by 15 natural rainfalls were observed and compared to model simulations in four plots with soils treated with solar-dried orange peel and in four without any treatments.

A very poor model performance was detected (with a strong tendency to overestimation of the hydrological observations) both in control and treated plots. However, WEPP model was found to be able to simulate the lower hydrological response after addition of OM to soils.

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## Spatial and seasonal variations of atmospheric legacy and current-use pesticides in central China: regional source vs. long-range transport and air-soil exchange

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**KEY WORDS:** Organochlorine pesticides; Passive air sampling; Air-soil exchange; East Asia monsoon

### Introduction

Organochlorine pesticides (OCPs) have been introduced into the environment through anthropogenic activities during the past several decades.

Despite the use of some OCPs being prohibited for decades, plain areas have become a severely contaminated zones, and have been converted into an important reemission source to atmosphere. Mountain areas can be regarded as some of the most pristine and remote ecosystems, far from the sources of pesticides.

The atmosphere is the primary pathway for the migration of OCPs from their source region to pristine areas. The Asian monsoon was hypothesized to exert great influence on long-range atmospheric transport (LRAT) of OCPs.

To explore the source-sink relationship of OCPs and its association with the monsoon, polyurethane foam (PUF) disk passive air samplers (PAS) were deployed to measure spatiality and seasonality of OCPs in Jiangnan Plain (JHP) and Western Hubei Mountain (WHM). In addition, the study explicated the contamination status of OCPs in the atmospheres of the JHP and WHM.

### Study area

JHP, located at the central part of Hubei, is a key national grain and cotton production center, where wide application of pesticides occur. The amount of pesticide used in the JHP has been estimated to be as high as ten thousand tons in the year of 2005. In recent years, the contamination of OCPs in topsoil, sediment and water of the JHP has been subject of many detailed research projects. These results verified the serious situation of environmental pollution by pesticide residue in the JHP.

WHM possesses a complicated nature and geographic environment, resulting in biodiversity richness. Compared to other regions of China, WHM is just slightly contaminated by pesticides, to which the relatively lower occurrences of diseases and pests can be attributed.

Dajiuhu (DJH), located at the western margin of WHM, is the largest and most preserved alpine wetland in central China. It is a relatively closed basin and original wetland, which creates beneficial conditions to elucidate the potential role of the plain area acting as the primary emitter of OCPs influencing the mountain area through LRAT.

### Passive air sampling

The sampling campaign was performed in central China with seven monitoring stations using polyurethane foam based passive air samplers (PUF-PAS) (Fig. 1). Detail on the PUF-PAS used in this study can be found elsewhere (Estellano et al., 2008). The sampling sites were monitored in four periods of approximately three-months (spring, summer, autumn, and winter) from 1st April 2012 to 22nd March 2013.



Fig. 1. Geographical locations of passive air sampling.

### Analytical procedure

The mixture of surrogate standards containing 2,4,5,6-tetrachloro-m-xylene (TCmX) and decachlorobiphenyl (PCB209) to quality ensure the method performance during extraction and clean-up procedures. PUF disk samples were extracted in a Soxhlet apparatus using dichloromethane (DCM). An alumina/silica (v/v=1:2) gel column was used to pure the eluate. pentachloronitrobenzene (PCNB) as an internal standard for instrument analysis was spiked.

The instrumental analysis of the target compounds were performed using an Agilent 7890A gas chromatograph with a 63Ni electron capture detector (GC- $\mu$ ECD) and a HP-5 MS capillary column (30 m length, 0.32 mm i.d., 0.25  $\mu$ m film thickness).

Seven OCPs were identified and quantified. These compounds were divided into 2 groups: I, legacy OCPs (p,p'-DDE, p,p'-DDD, o,p'-DDT, p,p'-DDT), II current-use OCPs ( $\alpha$ -Endosulfan,  $\beta$ -Endosulfan, Endosulfan sulfate).

The surrogate recoveries (mean+standard deviation) were  $69.8 \pm 9.2\%$  and  $85.7 \pm 15.7\%$  for TCmX and PCB209, respectively.

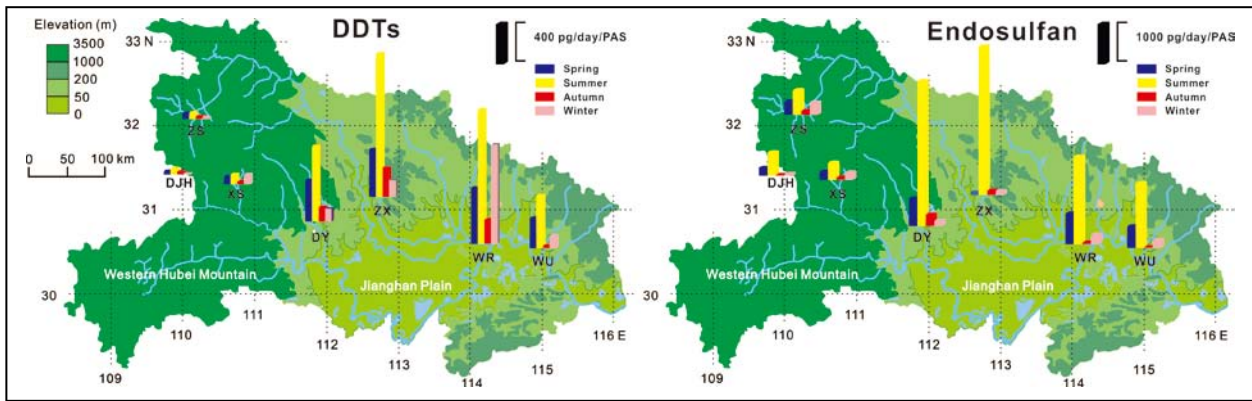


Fig.2. Spatial and temporal variations of atmospheric OCPs. DDTs means the sum of p,p'-DDE, p,p'-DDD, o,p'-DDT, p,p'-DDT, Endosulfan is the sum of  $\alpha$ -Endosulfan,  $\beta$ -Endosulfan, Endosulfan sulfate.

**Results and Discussion**

Significant geography-related differences (Mann-Whitney U test,  $P < 0.05$ ) in concentrations of DDTs was observed in the comparison between JP and WHM, and there was a significant seasonal variability (Kruskal-Wallis test,  $P < 0.05$ ) in atmospheric concentration of Endosulfan.

The concentration (pg/day/PAS) of DDTs in JHP (average=538) was higher than the value observed for WHM (average=55.6) (Fig.2). And Endosulfan ranged from 13.3 to 609 (average = 253), and from 17.0 to 3638 (average = 873) for WHM and JHP, respectively.

The peak concentration of DDTs and Endosulfan occurred over the JHP and WHM during the summer. Atmospheric Endosulfan displayed an increasing trend, whereas DDTs decreased obviously comparing with that of 2005.

The  $p,p'$ -DDT/( $p,p'$ -DDE+ $p,p'$ -DDD) ratios in JHP and WHM were all less than unity, and indicated the prevalence of aged technical DDT in the atmosphere. the  $\alpha/\beta$ -Endosulfan ratios were found to be 1.18 to 12.2 (average=5.32), indicated a combination of fresh applications (lower ratios) and an aged signature (higher ratios).

Generally speaking, o,p'-DDT, p,p'-DDT are at air-soil equilibrium. p,p'-DDE, p,p'-DDD,  $\alpha$ -Endosulfan show deposition to soil (Fig. 3).

The low ff values for  $\alpha$ -Endosulfan in JHP might be associated with farming activities. For the WHM, the low ff values implied that  $\alpha$ -Endosulfan originates from Endosulfan hotspot, which may act as the potential source controlling air-soil exchange of it in the area.

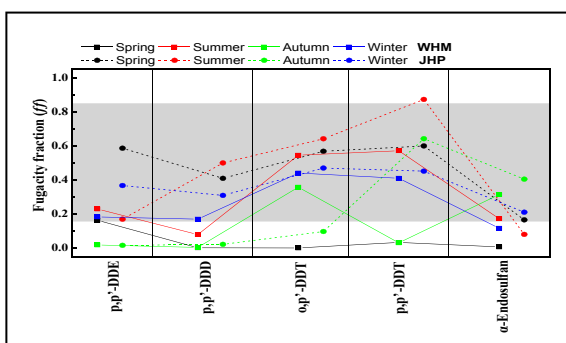


Fig. 3. Air-soil fugacity fractions.

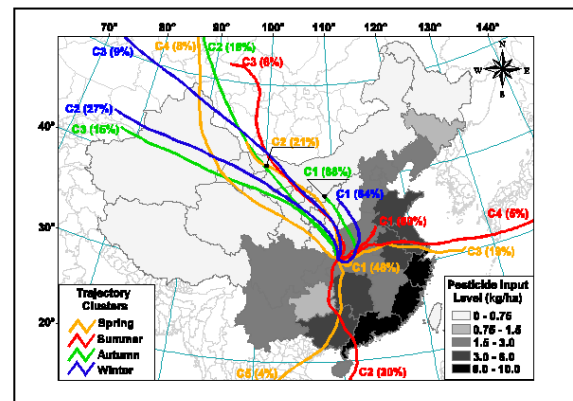


Fig.4. 5-day backward trajectory clusters plotted on the classification of pesticide application in different areas of China in 1996 (Tieyu et al., 2005).

The season variability of atmospheric DDTs and Endosulfan concentration could be explained by backward trajectories to a certain extent that probably passed through heavily contaminated areas. Furthermore, the shortest cluster (cluster 1) was the most frequent in all seasons, and passed through the JHP before arriving at DJH, indicating that the Jiangnan Plain can be recognized as a potential source of these chemicals to Western Hubei Mountain.

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