have been near the surface during most of the Cenozoic. This is confirmed by low temperature geochronology for the realm of the Koralpe. Hence the whole process of continental extrusion should be documented in this area in terms of brittle tectonic structures. The Paleogene and Neogene evolution of these unit is characterised by the formation of two major sets of faults: (1) ESE-WNW- to E-W- trending faults, associated with ENE- and NNW- trending conjugate structures and (2) N-S to NNE-SSW striking structures, mainly acting as high-angle normal faults, often associated with E-dipping low-angle normal faults along the western margin of the Styrian Basin.
Together with the stratigraphic evolution of the Styrian and Lavanttal Basins and the related subsidence histories a tectonic evolution may be reconstructed for this part of the Eastern Alps. During Oligocene to Karpatian times WNW- to W trending dextral strike-slip faults formed in the Koralm Massif due to ongoing lateral extrusion of the Eastern Alps. Troughs filled with coarse block debris formed along these faults due to reactivation as normal faults during consecutive N-S directed extension during Karpatian to Early Badenian times (approx. 17-15 Ma). During the Badenian pronounced normal faulting due to W-E extension lead to continued subsidence within the extrusion corridor.
In the Western Styrian Basin only minor areas with Sarmatian (13-11.5 Ma) sediments are observed; Pannonian (11.5 to 7.1 Ma) sediments are restricted to the Eastern Styrian Basin. This indicates, that the Koralm basement and the Western Styrian Basin were affected by post-Sarmatian uplift, coinciding with a reactivation of N- trending normal faults along the eastern margin of the Koralm Massif. Therefore, we suggest that the final uplift of the Koralm Complex, partly together with the Western Styrian Basin, occurred during the early Pannonian (at approximately 10 Ma). The present elevation of clastic deposits indicates that the Koralm Complex was elevated by approximately 800 m during this phase, associated with an additional phase of E-W-directed extension accommodated by N-S striking normal faults.

## Morphotectonical analysis of the Koralpe (Eastern Alps) - structural controls and implications for the uplift history

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The Koralpe Range at the eastern margin of the Eastern Alps shows in an E-W cross section an asymmetric topography. In map view the trapezoid shaped block of the Koralpe shows along its south-western segment steep slopes and short stream channels, whereas gentle slopes characterize the central and northern parts. Elongated, partly gorge-like catchments incise the mountain range along its eastern margin. In this study, the fluvial landscape which dissects this mountain range is characterized by stream long profiles and by analyzing the power-scale relationship between stream slope and drainage area. Additionally, the hypsometric integral and the basin asymmetry are calculated. The concave-up form of the stream long profiles suggests an equilibrium state of the fluvial landscape. However, the presence of knick points in some of the longitudinal profiles indicates disequilibria which may partly be related to differences in the erodibility of the bedrock and to relicts of glacial morphological elements in the uppermost regions of the Koralpe. Migrating knick points and profile adjustments due to a lowering in the base level or due to distinct fault offsets could not be verified yet. Hypsometric curves and integral values indicate a „mature“ state of landscape development. In accordance with a tectonic model describing the eastward tilting of the Koralpe as a consequence of Miocene block rotation, slope-area data from stream channels suggest a spatial differential uplift pattern. A north-to-south-increase of the steepness values suggests faster uplift rates in the central Koralpe. This trend is traced by Paleogene low-temperature geochronological data and by the Late Cretaceous metamorphic field gradient. Thus, it may be explained by a long-term spatial pattern of exhumation which remained stable since the Late Cretaceous. The calculated basin asymmetry factors (Hare & Gardner 1984) indicate strong asymmetry for several catchments in the eastern realm of the Koralpe. Because a directional trend can not be found in the current data, block tilting around an axis parallel to the approximately WNW-ESE oriented streams seems to be not the reason for the observed basin asymmetries. In contrast, the pronounced anisotropy of the metamorphic rocks and the large scale fold structures of the study area control the basin asymmetries.

Hare, P.W. & Gardner, T.W. (1984): Geomorphic indicators of vertical neotectonism along converging plate margins, Nicoya Peninsula, Costa Rica. - In: M. Morisawa & J.T. Hack (Eds), 15th Annual Binghamton Geomorphology Symposium. Allen and Unwin, pp. 90-104.

## Ist die Verteilung von Höhlentypen beiderseits der SEMP Störung ein Indiz für verschiedene Hebungsraten?

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In der vorliegenden Studie wurden vor- und hochalpine Gebirgsgruppen der Nördlichen Kalkalpen zwischen den Gesäuseberge im Westen und dem Schneeberg im Osten untersucht.
Die Karstmassive mit Seehöhen bis 2370 m haben großteils Plateaucharakter oder zeigen zumindest Reste von Altlandschaften. Die Flächen der Plateaus liegen in der Größenordnung von wenigen 10er km², wobei die größte der Hochschwab mit ~120 km² einnimmt. Die Gebirgsgruppen werden aus mittel- und obertriassischen Karbonaten aufgebaut, die durchwegs gut verkarstet sind. Das WSW-ENE streichende SEMP-Störungs-System (Salzachtal-Ennnstal-Mariazell-Puchberg) stellt ein wichtiges tektonisches Element dieses Gebietes dar. Es ist seit dem Miozän aktiv und weist einen sinistralen Versatz von ca. 60 km auf.
Für die Studie wurden nur Gebirgsgruppen auf beiden Seiten der SEMP Störung analysiert, deren Gipfel mehr als 1600 m aufweisen. Innerhalb dieser sind über 2600 Höhlen bekannt, wobei der Erforschungsstand in den meisten Gebieten als recht gut eingestuft werden kann. Rund 450 Höhlen, die eine Ganglänge von mehr als 50 m aufweisen, wurden nach ihrer Genese klassifiziert, wobei untersucht wurde, ob sie unter vadosen oder (epi)phreatischen Bedingungen entstanden sind. Das Hauptaugenmerk wurde auf (epi)phreatische Höhlen gelegt, die an ehemaligen Vorfluterniveaus gebunden sind und nicht an lokale geologisch bedingte Wasserstauer.
Das Verteilungsmuster zeigt, dass die primär vertikal entwickelten, vados entstandenen Höhlen in allen Gebieten auftreten, während vorflutgebundene phreatisch entstandene Höhlen nicht homogen verteilt sind. Augenscheinlich sind sie nördlich der SEMP Störung häufig, während sie südlich kaum vorkommen oder fehlen. Da diverse andere Gründe wie Klima oder lithologische Unterschiede ausgeschlossen werden können, scheint eine unterschiedliche Hebungsgeschichte bzw. paläogeographische Bedin-

gungen der beiden Einheiten nördlich und südlich der SEMP möglich. Weiters wäre es möglich, dass phreatische vorflutgebundenen Höhlen existierten, aber mit Sediment verfüllt wurden. Aufschlüsse verfüllter Höhlen scheinen südlich der SEMP häufiger zu sein. Dies würde ehemals unterschiedliche sedimentäre bzw. hydrologische Bedingungen beiderseits der Störung bedeuten.

## Determination and shape analysis of selected Terrestrial and Martian geomorphic features derived from high resolution DTMs

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The purpose of the study is the investigation of automated methods for the determination and shape analysis of morphological features. The methods' focus is the detection of peaks and pits (sinks) and the recognition of selected types of shapes. Additionally, some non-typical cartographic visualisation techniques aiming at the enhancement of morphological details were developed. The proposed methods allow for enhanced quality control and subsequent DTM quality improvement. Hence, the interpretation of terrain features for various applications may be supported.

The first part of the study focuses on detecting areas of peaks and pits (regional extremes) and describing their shapes. The determination of significant regional extremes, comprising more than one local property, is a more challenging task. To solve this task, we propose automated algorithms to deal with the topographic and morphological criteria properly. The points and potential surfaces of the regional extremes are calculated and shapes are identified. Advantages of the automated approach are that the parameters are standardised and the results are more comparative, more objective, and therefore of higher quality. The proposed techniques are compared with the techniques for the peaks detection with local histograms.

The second part introduces some enhanced visualisation techniques that are based on extracting selected morphologic characteristics of a landform. We propose visualization techniques that can be grouped as follows: relative relief modelling, enhanced height-coding including local approaches, techniques for the enhancement of edges or other morphological features enhancement. Furthermore, we propose DTM generalisation and multiscale presentation for visualization purposes. A combination of the proposed methods in various scales may improve reading and interpretation of landform features. Possible by-products are: objective DTM analysis, DTM quality improvement; support in DTM interpretation; possibility of application in education; and increase of the public awareness on environment.

Selected areas on the Mars have been investigated using DTMs determined from HRSC images and MOLA data in the areas of Candor Chasma and Nanedi Valles. For the calibration of the parameters the following areas on the Earth were analysed in previous stages: San Francisco volcanic fields in Arizona, Vorarlberg, Austria and Kamnik Alps in Slovenia. As the morphological features on Mars are often different compared to the Earth, the acquired knowledge from Mars will help to better understand the Earth's characteristics, and can be therefore used for better modelling the DTMs on Earth.

## An attempt of analysis of the potentially hazardous detrital cones (fans and talus cones) with DTM in Alpine areas

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In alpine settings where the topographic evolution is mostly driven by post-glacial geomorphology, the analysis of digital terrain data has attracted much interest. Unstable valley slopes are often covered by detrital cones (fans). In these areas the scree slopes are often unvegetated, however in some settings of young forests or shrubs may cover them. Less active and often settled fans that are analysed in this study are characterised with less risk potential.

Identification of the fans has been carried out by introducing appropriate spatial variables derived from a high quality DTM (e.g. slope, relative relief, aspect, curvature, etc.). The combinations of different variables by modelling in GIS environment enable outline the potential areas of fans. The output may be twofold: On one hand the detection of the potential talus cone areas that are important for geomorphic assessment. The second aspect is the visualisation of the terrain surface with enhanced terrain structures in order to provide easy-to-read maps of the fans including explanatory text that increases public awareness on the possible natural hazards.

The preliminary results of calculations are promising. Map algebra operations of sectorial parameters yielded the best results. The vast majority of the talus area has been categorized by the method to the correct category. The misclassifications are relatively rare, and they appear rather as single points, than in extensive patches. It seems that later they can be removed applying a simple filter. Although we present here the results of relative small test areas, the method works also in larger extents as well. On the other hand the processing of larger area needs more preparation time of the operator, since misclassifications may occur. Especially if various lithological classes are present in the area to be processed, the results cannot remain always stable, because the modelling may turn to be selective in the area of one lithology, and in the area of another rock type the classification selects too many or too few points. This behaviour should be eliminated in operational environment.

## The Tonalitic lamellae along the Giudicarie Fault System

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The NNE-SSW striking Guidicarie Fault System (GFS, composed