Sedimentology of a Miocene delta complex: The type section of the Ingering Formation (Fohnsdorf Basin, Austria)

Monika HÖLZEL & Michael WAGREICH

Department of Geological Sciences, University of Vienna, UZA II - Althanstr. 14, 1090 Vienna, Austria
email: monika.hoelzel@univie.ac.at

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Abstract

The Ingering Formation (Middle Miocene, Early - Middle Badenian) forms part of the Neogene basin fill of the intramontane Fohnsdorf Basin in Styria (Austria). Outcrops mainly occur at the northern margin of the basin, where the type section is situated on the banks of the river Ingering.

In the lower parts of the formation, pelitic rocks comprising *Congeria* breccias and thin sandy layers of a prodelta facies dominate the succession. They are overlain by sandy units with cross bedding interpreted as delta front facies, which grades into quartzite conglomerates and gravelly sands of a delta front to delta plain facies. All these deposits can be interpreted as forming part of a southward prograding delta complex into a lake. Heavy mineral and grain size data indicate that the sediments were transported over a short distance and were derived mainly from the northwest, i.e. the Wölz and Rappolt metamorphic complexes.

Breccia layers, up to 3 m thick, within the lower parts of the prodelta facies are mainly composed of the bivalve *Congeria* and host minor angular clasts (mainly gneisses, mylonites, quartzites). These sub-aquatic debris flows are the result of short-term, event-triggered deposition, which disturbed the quiet and steady deposition of the pelitic lake sediments. Soft-sediment deformational structures such as boudins, S-verging folds, rotated faults and rotated clasts occur within these *Congeria* breccias. They result from increasing sediment load and additional southward sediment failure of mass flows on a depositional slope.

1. Introduction

The Ingering Formation (Sachsenhofer et al., 2000a; Strauss et al., 2003) forms part of the Neogene basin fill of the Fohnsdorf Basin (Styria, Austria, see Fig. 1). With an area of 120 km² and a depth of ~2 km (Sachsenhofer et al., 2000a,b) the Fohnsdorf Basin is the largest intramontane basin along the Mur-Mürz fault system. The deposits of the Ingering Formation provide a good example of a delta prograding into an intramontane lake within a pull-apart basin.

The main focus of this work is to understand the dynamic evolution of the delta complex of the Ingering Formation type section along the banks of the Ingering river, NW of Knittelfeld (Fig. 1). The integration of sedimentological data with recent data from reflection seismic lines (Sachsenhofer et al., 2000b), borehole data (Sachsenhofer et al., 2003), geochemical analyses (Weiss, 2002), geochronology (Ebner et al., 2002), and structural and stratigraphic data (Strauss, 2000; Strauss et al., 2001, 2003) facilitated our aim of refining and reconstructing the depositional system of the Ingering Formation.

2. Geological setting

The Fohnsdorf Basin is situated at the crossing point of two major strike-slip fault systems, the E-W-trending Mur-Mürztal Fault and the NNW-SSE-trending Lavanttal Fault. It is situated amongst Austroalpine metamorphic complexes, i.e., the Seckau Complex and Wölz Complex in the N, the Ammering-Speik Complex in the SE, and the Rappolt Complex in the W (Fig. 1). The basin developed in the Miocene during the lateral escape of the Eastern Alps (e.g. Ratschbacher et al., 1991). Subsidence began in the Early to Middle Miocene with a pull-apart stage coeval with the opening of the Seckau Basin. This was followed by a halfgraben stage, when the Seckau Basin was separated from the Fohnsdorf Basin, while the final stage was compressive (Strauss et al., 2001). The Fohnsdorf Formation (Upper Karpatian to Lower Badenian; Strauss et al., 2003), about 800m thick, and the Ingering Formation (Lower/Middle Badenian; "Hangendschichten" of Polesny, 1970), about 2000 m thick, were deposited during the pull-apart stage. These formations are overlain by the coarse-grained Apfelberg Formation (Middle?/Upper Badenian, ~1000 m), which was deposited during the halfgraben stage (for overviews on lithostratigraphy, see Sachsenhofer et al., 2000a; Strauss et al., 2003).

3. Ingering Formation type section - an overview

The type section of the Ingering Formation crops out along the western banks at the Ingering river N of Knittelfeld (Massweg, municipality Spielberg) over a distance of 1.2 km. The total measured thickness attains 156 m (excluding Quaternary). This comprises half of the in situ conserved part of the Ingering Formation along the Ingering river (320 m; see Fig. 2). When compared with published borehole data and seismic sections (Sachsenhofer et al., 2000a,b; Sachsenhofer et al., 2003) the outcrops in the Ingering Formation type section form part of the lowermost Ingering Formation. The upper part is only known from boreholes (Weiss, 2002; Sachsenhofer et al., 2003), since there exist no surface outcrops.

The lower boundary of the Ingering Formation, which has been defined by the change from a several metre thick coal bed to dark grey and black shales, is not exposed in the type section. The coal seam was mined in the "Bergbau Knittelfeld", north-east of the Ingering river (Weber and Weiss, 1983).

Through the entire Ingering Formation type section a coarsening-upward trend is observed, although in the upper part there are still thick units of fine sediment present. The base of the section comprises dark grey laminated shales and mudstones with thin sandy layers (Fig. 3a) and includes an orange to light grey tuff layer (~5 cm, see Fig. 2 - section Ingering 1). Overlying the shales and mudstones are a series of up to 3 m thick breccia beds (18 - 22.5 m) alternating with grey shales. These coarse-grained beds include significant deformational structures and three coalified root stocks (Fig. 3b). Above the breccia beds, mudstones and shales are exposed, but coarser-grained sand layers become more frequent and thicker, and the amount of shale beds decrease gradually. Partly cross-bedded sand layers (~180 - 215 m, Fig. 3c) dominate the upper part of the type section (> 118 m). Above an intraformational unconformity (~215 m) another interval of shales and mudstones follows, overlain by a succession of conglomerates and on top layers of mudstones and shales, including some tuff horizons (2 - 10 cm). The beds are consistently shallow dipping to S (Mean 188/20), which has been interpreted as the result of tectonic tilting during the halfgraben phase (Strauss et al., 2001).

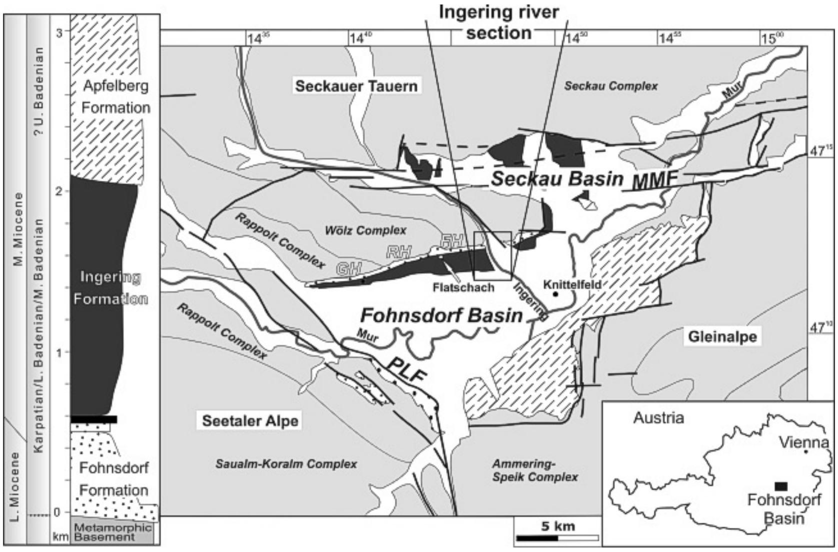

Figure 1: Geological sketch map of the Fohnsdorf Basin area and stratigraphy of the Neogene basin fill (modified from Sachsenhofer et al., 2000a,b; Strauss et al., 2001; Strauss et al., 2003). The Ingering Formation is marked in black colour. MMF = Mur-Mürz-Fault; PLF = Pöls-Lavanttal-Fault; GH = Gaal High; RH = Rattenberg High; FH = Flatschach High.

The upper boundary of the Ingering Formation is marked by an angular unconformable contact of coarse conglomerates with block-bearing gravels of the Apfelberg Formation (Polesny, 1970; Strauss et al., 2003).

4. Facies assemblages of the Ingering Formation type section

4.1. Mudstones and shale with thin sandy layers

The lower part of the Ingering Formation type section (< 118 m) is dominated by laminated grey/brown mudstones and shales, which are more or less indurated. Bedding planes are often covered by detrital muscovite and/or plant remnants and small coaly pieces. The sediment is laminated at the mm-scale, but there are no other sedimentary structures and bioturbation is very minor. Between these beds thin fine-grained sandstone layers with ripple lamination are present, which indicate a sediment transport direction from N-NW (mean 156/29). The thickness of these layers varies from millimetres to a maximum of about 10 centimetres; isolated ripples are present.

4.2. Congeria breccia

Up to 3 m thick mollusc-bearing breccia beds (Fig. 3b) interrupt the succession of laminated dark clays. These breccia interlayers display varying amounts of partly broken mollusc shells and allogenic rock fragments (~15 % of components) derived from the northern Austroalpine metamorphic basement. The bivalve genus *Congeria* (mainly *Congeria cf. antecroatica;* Polesny, 1970) makes up more than 90 % of the mollusc assemblage. Associated fossils include *Theodoxus crenulatus* and other gastropods, ostracods and bivalves (e.g. *Physa norica*). In one bed (Nr. 105 at 18.5 m) remnants of brown algae, which live in freshwater to brackish environments (pers. comm. Baal and Zuschin, 2003) were found (Fig. 4). The calcite shells are replaced by dolomitic material and show no preferred orientation.

Allogenic clasts, including mainly gneisses, mylonites and quartzites, display angular to very angular shapes. They are embedded in a finer-grained matrix, without preferred orientation, but some of them display long axis perpendicular to bedding. A mixture of *Congeria* shells and fine-grained silty to sandy material makes up the matrix of the coarse beds. In coarser-grained intervals densely packed *Congeria* shells form the matrix for larger allogenic clasts. Bed thicknesses vary from centimetre- to metre-thick beds and from weakly cemented layers with 90 % broken molluscs to matrix supported layers, where shells are embedded in silty material. The bases of coarse breccia beds are mainly non-erosional and the upper portions sometimes display normal grading from gravel to fine sandstones.

4.3. Sand dominated facies

In the upper part of the type section (> 118 m), there is a change to more sand-dominated deposits. Medium- to coarse-grained sands and weakly-cemented sandstones comprise mainly quartz and muscovite components. Siginificant amounts of detrital biotite is present only in the uppermost part of the section.

Sands and sandstones display mainly massive to thick-bedded strata up to several meters in thickness often in combination with large scale tangential cross bedding with sets up to 3 m in thickness (~180 - 215 m, Fig. 3c). Cross bedding indicates transport directions from W to NW. Coal pieces and mm-thin coaly layers are common as well as gravel lenses with erosional structures which are interpreted as small channels.

4.4. Gravel dominated facies

Medium to coarse conglomerate to gravel are made up by components of about 70 % quartz, 20 % amphibolite and 10 % mica schist fragments. Components are subangular and the sediment, which displays crude horizontal bedding, is partly matrix supported and partly clast supported. The matrix is mainly fine- to medium-grained sand. Neither grading nor imbrications were found.

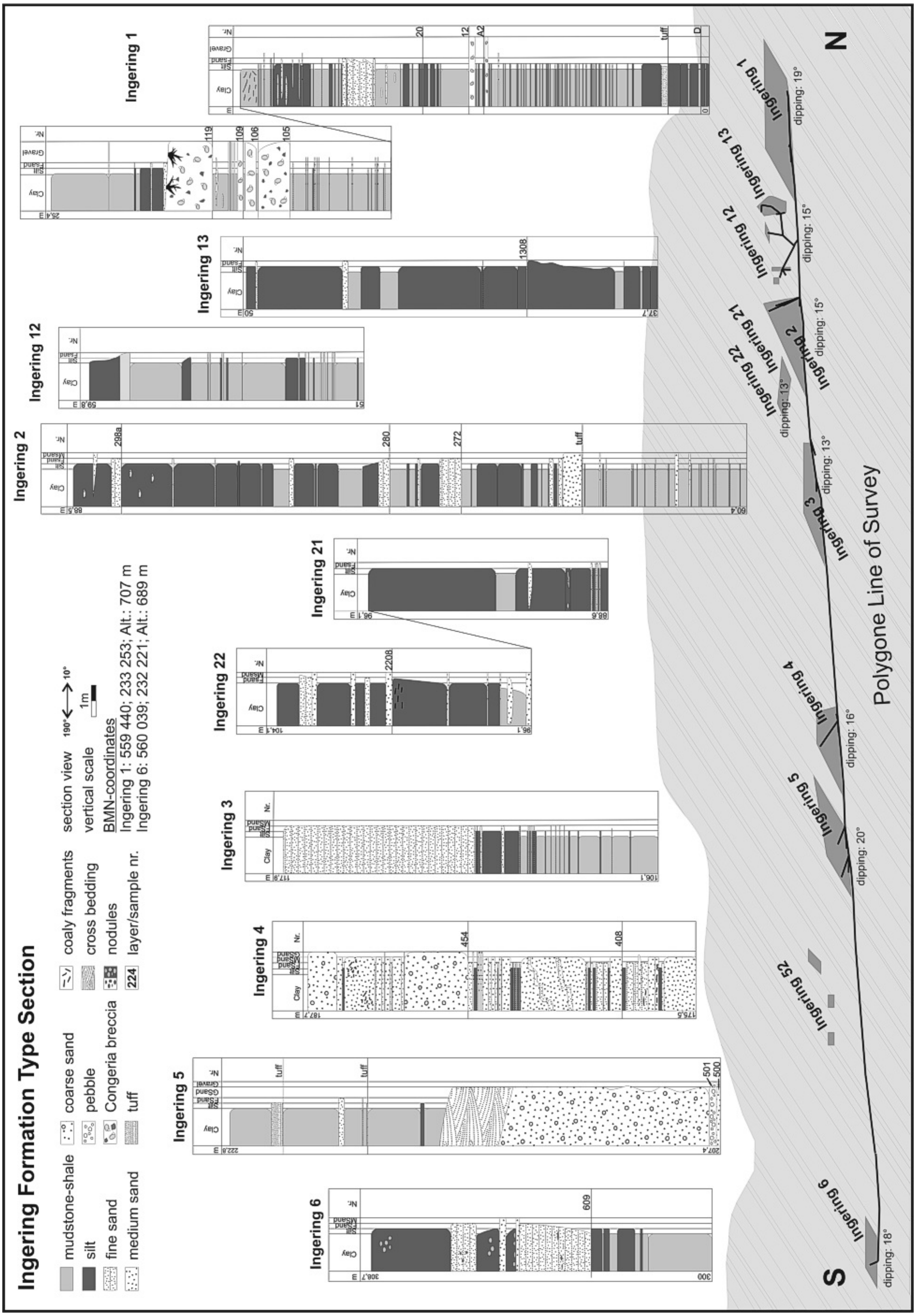

FIGURE 2: Composite type section of the Ingering Formation in combination with a sketch of the cut banks of the Ingering river, illustrating the surveyed outcrops. The sections are generated using the software StratDraw (Hölzel, in press).

4.5. Tuff

The investigated section comprises at least 4 tuff layers (see Fig. 2; Ingering 1: 1.5 m; Ingering 2: 65.6 m; Ingering 5: 218.1 and 309.6 m), which are light blue-grey or altered orange. The layers are up to a few centimetres thick (max. 10 cm) and they comprise varying amounts of fine-grained quartz, muscovite and biotite. Zircons from another tuff layer within the Ingering Formation (Flatschach outcrop, see Fig. 1) were dated as 14.9 ±0.8 Ma (Middle Miocene, Ebner et al., 2002) using fission track analysis.

5. Deformational Structures

Soft-sediment deformation occurs in the lower part of the Ingering Formation type section (< 26 m). The most interesting outcrop (Ingering 1: BMN 559.440; 233.253; Sh.: 707 m; ~100 m long, exposed rocks 25.4 m thick) include breccia beds alternating with clay-silt layers. Individual beds display strong variations in thickness and some layers are interrupted or pinch out laterally over a few meters.

Boudinages of up to 3 m thick breccia beds and pinch and swell structures with faults at their necks with a constant dip towards NW (mean 303/39) indicate layer parallel extension. In contrast layer parallel shortening is indicated by ptygmatic folding of thin, fine-grained breccia layers. Most of these folds are S to SE verging, confirming a shearing component during deformation of the sediments in a southern direction. This layer parallel shortening and extension occurs within the same layers.

Another type of deformational structure developed around angular metamorphic rock fragments within the breccia beds, which have a diameter of up to 24 cm (Fig. 5). Clay layers encircle some of these angular clasts or are interrupted by slumped or protruded clasts. Although genetically unrelated the shape of these clasts geometrically resembles δ-clasts (Fig. 5), which are mantled porphyroclasts, typical of greenschist facies mylonitic rocks. δ-clasts generally reflect a rotation of the clast and a convex and concave distortion of the wings dependent on the rotation sense. The resulting monoclinic geometry is considered to be a reliable shear-sense criterion (e.g. Passchier and Trouw, 1996).

As a rather new attempt for investigating soft-sediment structures a numerical model was calculated based on a 14 x 24 cm large, trapezoidal shaped mylonite clast. Results indicated layer parallel extension and compression within the same layers due to increasing sediment upload and slumping (for details see Hölzel, 2003).

6. Results and discussion – the Ingering Formation

The sediments of the Ingering Formation have been interpreted as resulting from delta filling of an intramontane lake (Sachsenhofer et al., 2000a,b; Strauss et al., 2001). Based on process-oriented terminology (e.g. Reading, 1988) deltaic regimes can be divided into the delta plain - a largely subaerial zone dominated by rivers, the delta front - the zone of interaction between fluvial and basinal processes, and the prodelta - the zone of quiet sedimentation from suspension disturbed only by gravity sliding and mass flow deposition. The sediments of the Ingering Formation were deposited in a river delta, which was governed by the infill of clay, silt and sand (see Fig. 6), with a shallow gradient, short term catastrophic events and soft-sediment deformation. A southward prograding trend is evident both from the interpretation of seismic sections (Sachsenhofer et al., 2000b), but also from ripples within thin sandy prodelta layers, cross-bedding and deformational structures, such as S-verging folds and N-dipping faults (Ingering Formation type section; Hölzel, 2003).

The sediments in the lower part of the Ingering Formation (< 600 m;

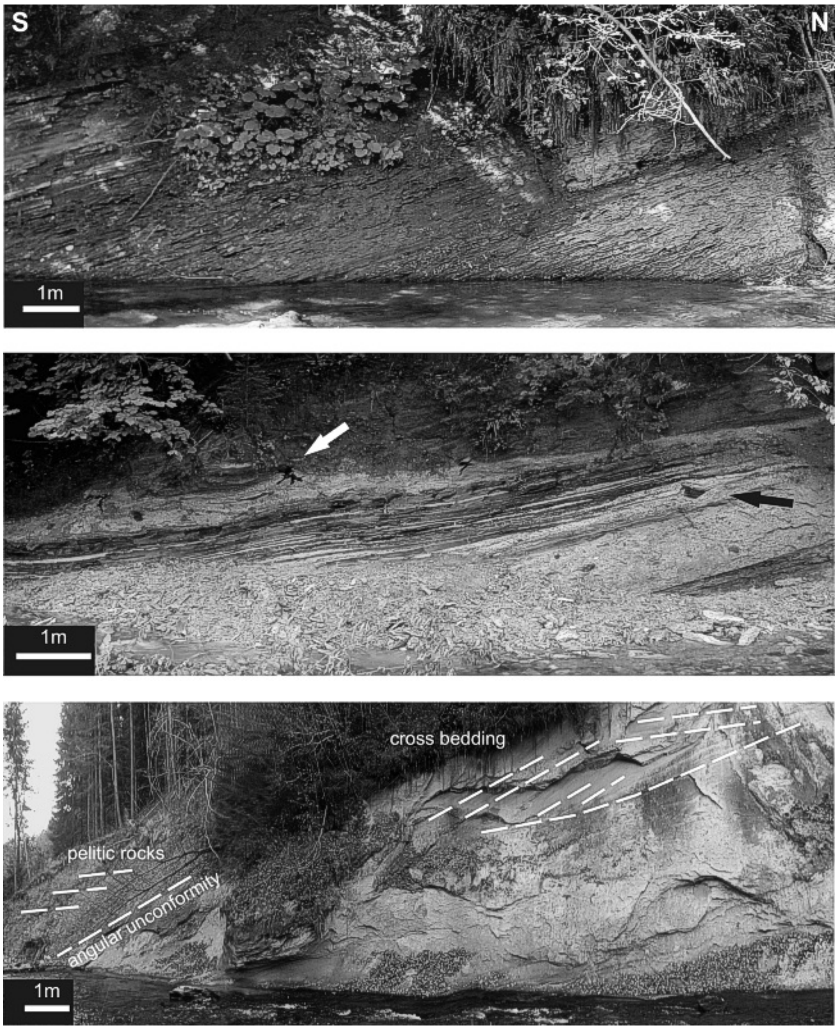

Figure 3: Pictures of characteristic outcrops at the cut banks of the Ingering river (N-Knittelfeld). a) Outcrop Ingering 1 with mainly pelitic rocks of the prodelta facies, gently dipping to S. b) Alternating Congeria breccias and pelitic rocks of the upper part of outcrop Ingering 1, displaying gneiss clasts within the breccia beds (black arrow) and coalified root stocks (white arrow). c) Outcrop Ingering 5, displaying the coarse deposits of the delta front. Cross bedding is outlined for clarity. Note the angular unconformity between the sand beds and the pelitic succession in the background.

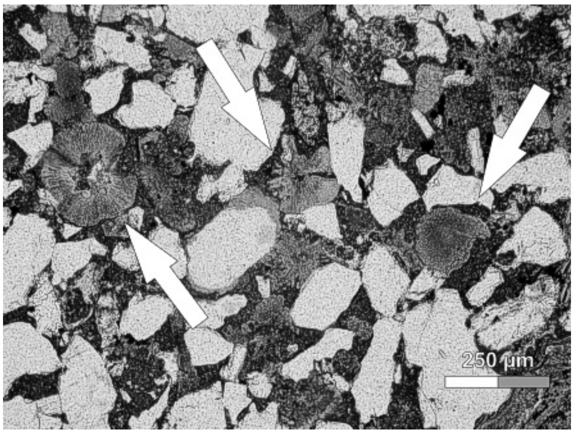

Figure 4: Thin section photograph of a Congeria breccia with brown algae, indicating brackish to freshwater environment.

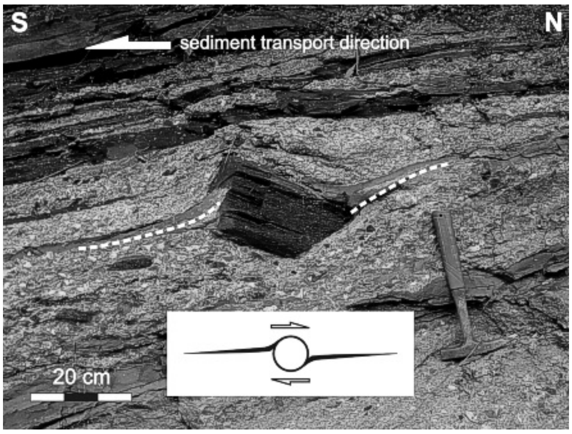

Figure 5: Paragneiss clast embedded in Congeria breccia bed and pelitic rocks. This clast was used for numerical modelling of deformation. Note the similarities to geometries of a δ-clast in metamorphic rocks.

well Gabelhofen; Sachsenhofer et al., 2003) comprise distal prodelta sediments, characterised by steady deposition of fine-grained brackish to lacustrine lake sediments. Laminations are generated by alternating deposition of clay and silt material from suspension (Hölzel, 2003). Rare thin rippled sandstone beds can be attributed to single flood events, transporting sandy material into the lake by turbiditic underflows. Because of partly dysoxic conditions in the lake (Sachsenhofer, et al., 2003) lamination is preserved and bioturbation is absent or scarce. The eroded parts of the Ingering Formation in the N, especially in the Seckau Basin, may have represented the coeval proximal prodelta or delta plain deposits.

As previously noted, a series of *Congeria* breccia beds (at c. 370 m of Ingering Formation) are interfingering with the fine-grained prodelta unit. These breccia beds show clear signs of deposition as mass flows, which may be related to extreme flooding events or soft-sediment failure of the upper parts of the delta. The main breccia beds can be interpreted as subaquatic initially, cohesive debris flows (sensu Nemec and Steel, 1994), which partly evolved into turbiditic flows. As a consequence of mass flow in a lacustrine delta mixing with a passive water body and previous lake sediments, the water content increases and the mass flow changes its behaviour (Nemec and Steel, 1994). Poor sorting and the absence of an erosional surface between the shales and the breccias are arguments for a debris flow interpretation (e.g. Pratson et al., 2000), whereas normal grading, especially of the uppermost parts of the beds, indicate turbiditic flow conditions. Additionally, the habitat of *Congeria* is that of a brackish shallow water milieu, which does not fit with the rather deep-water prodelta conditions (Weiss, 2002; Sachsenhofer et al., 2003) in the depositional area. The clasts, especially the amphibolites, indicate a provenance region in the area of the Wölz-Rappolt Complex (pers. comm. Schuster, 2003), north of the Fohnsdorf Basin. The angularity of the components is indicative of a short transport distance and/or rapid transport.

In section Ingering 1 soft-sediment deformation occurs. If deformation structures are formed very soon after or even coeval with deposition, then deforming stresses commonly relate to the same processes that deposited the sediment (Maltman, 1994). Therefore, in this situation, the deformation may be interpreted in terms of southward-directed slumping on the delta slope, which could have been caused by slope instabilities or loading by concurrent debris flows (sensu Martinsen, 1989) and may have been triggered by earthquakes due to ongoing strike-slip tectonism .

A moving slump gets intensely deformed internally, and produces a wide variety of deformational structures, such as folds, boudins, internal shear surfaces and faults (Maltman, 1994). All of these structures are present in the section. Numerical modelling suggests dominant pure shear progressive deformation (for further detail see Hölzel, 2003) Calculations indicate that during soft-sediment deformation the initial thickness of the sediments was reduced by more than 30 %.

The upper part of the type section includes deposits of the prograding delta front, which is indicated by the coarser grain size and the foreset bedding, characterized by large-scale cross bedding with 2-3 m sets. Intercalated clay intervals suggest the existence of sandy to gravelly delta lobes and contemporaneous intra-lobe fine-grained sedimentation or phases of decreased coarse siliciclastic input onto the delta front.

The graphic correlation of grain size distributions and transport regime (CM-

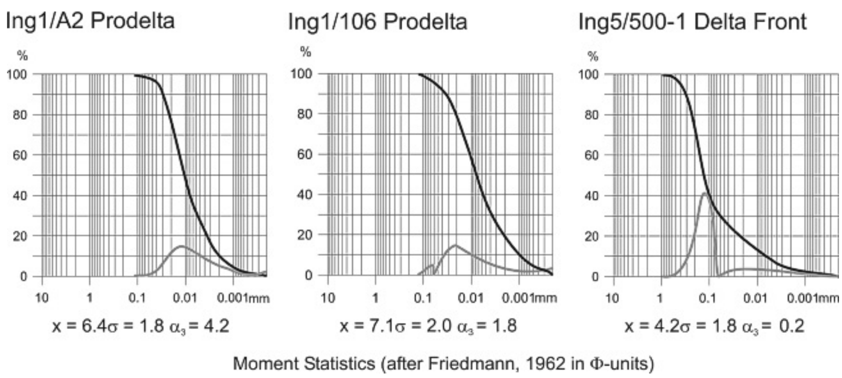

Figure 6: Grain size curves of representative samples of the Ingering Formation (for sample locations see Fig. 2). Moment parameters: x = mean, σ = standard deviation, α_3 = skewness/kurtosis.

Diagram; Passega, 1957; 1964; Passega and Byramjee, 1969) for the pelitic sediments suggests transport in homogenic suspension, which corresponds to steady deposition in the lake. This transport mode changes into transport in suspension in deeper water, which resembles a deepening of the lake with quiet sedimentation. The coarser-grained parts of the delta front display mainly characteristics for rolling transport (Fig. 7).

Results from heavy mineral analyses (Fig. 8; Tab. 1) confirm sediment input from the area of the Wölz and Rappolt complexes to the northwest. Angular to subrounded garnet and apatite dominate the assemblages, which were derived from garnet-micaschists in this region. Filling from the Seckau Tauern can be largely excluded, because of the low contents of zircon (pers. comm. Schuster, 2003). The mainly angular minerals suggest a short transport and no refurbishment of older sediments, which is also indicated by the poor to very poor sorting (classification of Friedman, 1962). This immature sediment character dominates in the whole section, in the laminated sediments of the prodelta as well as in the sands of the delta front. Only in the upper part of the Ingering Formation which not exposed in the type sections there exist more mature quartz-rich, well-rounded gravels (Polesny, 1970).

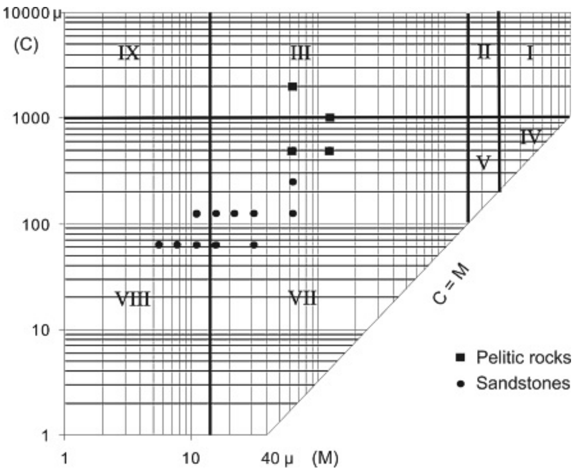

FIGURE 7: Grain size characteristics of samples from the Ingering Formation in the CM-Diagram after Passega and Byramjee (1969). This diagram is a graphic method to determine the depositional mode (C represents the one percent percentile and M the median of the grain size distribution).
I, II, III and IX are fields of rolling transport, little suspension or short transport. Fields IV, V, VI, VII represent transport in graded suspension and VIII homogenous and pelagic suspension.
The pelitic sediments plot into field VIII, which corresponds to quiet deposition by graded suspension in a lake. The pelitic rocks of field VII show deeper water and also quiet sedimentation. In field III there are samples from the upper, coarser part of the Ingering Formation, which display characteristic features of rolling transport.

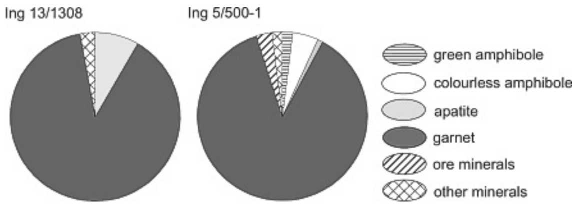

FIGURE 8: Representative heavy mineral data from the base (Ing13/1308) and the top (Ing5/501-1) of the Ingering Formation type section showing the continuous domination of garnet. Heavy minerals (0.0063-0.125 mm fraction) were separated with Tetrabromethane (ρ = 2.97 g/cm³). At least 200 translucent grains were counted.

7. Summary – Development of the Ingering Formation

The sedimentation of the Ingering Formation started with a thin interval of sapropelitic dark clays above a coal seam on top of the Fohnsdorf Formation (Sachsenhofer et al., 2000a,b), which records a subsidence pulse and a resulting drowning in the Fohnsdorf Basin during Lower to Middle Badenian (Strauss et al., 2001). During this time a connection from the Fohnsdorf Basin into the marine Lavanttal Basin existed along the Pöls-Lavanttal-Fault, which led to brackish conditions of the lake in the Fohnsdorf Basin (Weiss, 2002; Sachsenhofer et al., 2003). Delta sedimentation prograded from the north into this brackish to lacustrine basin ("Lake Ingering", up to ~ 600 m deep, Sachsenhofer et al., 2003). Fine-grained sediments derived from the northwest were transported into the lake and are recorded as pro-delta clays and silts in the Ingering Formation type section. At least two thick *Congeria* debris flows interrupted the steady sedimentation probably as a result of delta front and slope instability and active tectonism in the basin. This unit is affected by soft-sediment deformation resulting in a reduction of thickness of minus 30%.

Delta progradation continued towards the basin centre as indicated by the coarsening upward trend in the type section as well as by borehole data of Sachsenhofer et al. (2000a,b). Clay-rich stratal packages in the upper parts of the type section suggest the presence of more quiet depositional environments characterised by fine-grained deposition from suspension between shifting active sandy delta lobes.

Sachsenhofer et al. (2003) reported a change from brackish to freshwater conditions within the Ingering Formation type section based on geochemical analysis. In the type section sediments with brackish character are not as thick as in the southern well Gabelhofen (type section: up to outcrop Ingering 2 about 400 m; well Gabelhofen 480 - 680 m). This indicates a southward retreat of the brackish

Sample/Mineral	Ing1/12	Ing1/20	Ing13/1308	Ing2/250	Ing2/272	Ing2/280	Ing2/298a	Ing22/2208	Ing4/408	Ing4/454	Ing5/500-1	Ing5/500-2	Ing5/501	Ing6/609
Epidote	0	5	0	24	14	9	0	0	0	0	0	0	0	0
Clinozoisite	0	0	0	20	25	24	0	0	0	0	0	0	0	0
Amphibole green	2	13	0	2	1	0	3	2	4	3	2	0	0	0
Amphibole colourless	0	12	0	6	4	8	1	1	4	2	5	3	2	0
Apatite	13	32	8	23	8	18	4	15	4	1	1	19	6	50
Zircon	0	3	0	0	1	0	0	0	0	0	0	0	0	0
Rutile	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Tourmaline	5	0	0	0	0	0	0	0	0	0	0	4	0	19
Garnet	81	34	89	24	48	34	88	82	85	84	87	76	81	31
Pyroxene	0	1	0	1	0	1	0	0	0	0	0	0	0	0
Ore Mineral	0	0	0	0	0	0	0	0	0	0	3	0	2	0
Others	0	0	3	0	0	6	3	0	2	9	2	0	8	0

TABLE 1: Heavy mineral data from the Ingering Formation type section. (0.0063 - 0.125 mm grain size fraction; at least 200 transparent mineral grains counted per sample; other minerals include brookite, kyanite, staurolite).

environment during delta progradation, which intensified the freshwater influence.

During the subsequent extensional half graben stage (Middle/ Upper Badenian?; Strauss et al., 2001, 2003) the sediments of the Ingering Formation were tilted towards the south. The formerly continuous delta complex was divided by an uplifting ridge, which separated the Fohnsdorf Basin from the Seckau Basin (Fig. 1: Flatschach, Rattenberg and Gaal Highs; Strauss, 2000). Large parts of the Ingering Formation were eroded during this time interval, as suggested by the unconformable transgression of the Apfelberg Formation onto stratigraphically lower parts of the Ingering Formation.

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References

Ebner, F., Dunkl, I., Mali, H. and Sachsenhofer, R.F., 2002. Stratigraphic evidence of pyroclastic layers in Miocene basins of the Eastern Alps. Proceedings of the XVII Congress Carpathian-Balkan Geological Association, Bratislava.

Friedman, G.M., 1962. On sorting, sorting coefficients, and the lognormality of the grain-size distribution of sandstones. Journal of Geology, 70: 737-753.

Hölzel, M., 2003. Sedimentologische Bearbeitung der Ingering-Formation am N-Rand des Fohnsdorfer Beckens, Steiermark, Österreich. Diploma Thesis, University of Vienna, 79 pp.

Hölzel, M. (in press). StratDraw - Automatic generation of stratigraphic sections from tabulated field data. Computers & Geosciences.

Maltman, A. (Editor), 1994. The Geological Deformation of Sediments. Chapman & Hall, London, 362 pp.

Martinsen, O.J., 1989. Styles of soft-deformation on a Namurian (Carboniferous) delta slope, Western Irish Namurian Basin, Ireland. In: M.K.G. Whateley and K.T. Pickering (Editors), Deltas: Sites and Traps for Fossil Fuels. Geological Society of London Special Publications, pp. 167-177.

Nemec, W. and Steel, R.J., 1984. Alluvial and coastal conglomerates: their significant features and some comments on gravelly mass-flow deposits. In: E.H. Koster and R.J. Steel (Editors), Sedimentology of Gravels and Conglomerates. Canadian Society of Petroleum Geologists Memoir, pp. 1-31.

Passchier, C.W. and Trouw, R.A.J., 1996. Microtectonics. Springer, Berlin, 289pp.

Passega, R., 1957. Texture - a characteristic of clastic deposition. AAPG Bulletin, 41(9): 1952-1984.

Passega, R., 1964. Grain size representation by CM patterns as a geological tool. Journal of Sedimentary Petrology, 34(4): 830-847.

Passega, R. and Byramjee, R., 1969. Grain-size image of clastic deposits. Sedimentology, 13: 233-252.

Polesny, H., 1970. Beitrag zur Geologie des Fohnsdorf-Knittelfelder und Seckauer Beckens. PhD Thesis, University of Vienna, 234 pp.

Pratson, L.F., Imran, J., Parker, G., Syvitski, J.P.M. and Hutton, E., 2000. Debris flows vs. turbidity currents: a modeling comparison of their dynamics and deposits. In: A.H. Bouma and C.G. Stone (Editors), Fine-grained turbidite systems. AAPG Memoir, pp. 57-71.

Ratschbacher, L., Frisch, W., Linzer, H.-G. and Merle, O., 1991. Lateral extrusion in the Eastern Alps, 2. Structural analysis. Tectonics, 10: 257-271.

Reading, H.G. 1998. Sedimentary Environments. Blackwell Sciences, Oxford, 704 pp.

Sachsenhofer, R.F., Strauss, P., Wagreich, M., Abart, R., Decker, K., Goldbrunner, J.E., Gruber, W., Kriegl, C. and Spötl, C., 2000a. Das miozäne Fohnsdorfer Becken - Eine Übersicht. Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten Österreichs, 44: 173-190.

Sachsenhofer, R.F., Kogler, A., Polesny, H., Strauss, P. and Wagreich, M., 2000b. The Neogene Fohnsdorf Basin: Basin formation and basin inversion during the lateral extrusion in the Eastern Alps (Austria). International Journal of Earth Sciences, 89: 415-430.

Sachsenhofer, R.F., Bechtel, A., Reischenbacher, D. and Weiss, A., 2003. Evolution of lacustrine systems along the Miocene Mur-Mürz fault system (Eastern Alps, Austria) and implications on source rocks in pull-apart basins. Marine and Petroleum Geology, 20(2): 83-110.

Strauss, P., 2000. Das Fohnsdorfer Becken. Unpubl. Dipl. Thesis, University of Vienna, 59 pp.

Strauss, P., Wagreich, M., Decker, K. and Sachsenhofer, R.F., 2001. Tectonics and sedimentation in the Fohnsdorf-Seckau basin (Miocene-Austria): from a pull-apart basin to a half-graben. International Journal of Earth Sciences, 90: 549-559.

Strauss, P.E., Daxner-Höck, G. and Wagreich, M., 2003. Lithostratigraphie, Biostratigraphie und Sedimentologie des Miozäns im Fohnsdorfer Becken (Österreich). In: W.E. Piller (Editor), Stratigraphia Austriaca. Österreichischen Akademie der Wissenschaften, 111-140, Vienna.

Weber, L. and Weiss, A., 1983. Bergbaugeschichte und Geologie der Österreichischen Braunkohlevorkommen. Archiv für Lagerstättenforschung Geologische Bundesanstalt 4: 1-317.

Weiss, A., 2002. Marin versus nicht-marin: Untersuchung am Beispiel ostalpiner Neogenbecken. Diploma Thesis, Montanuniversität Leoben, 118 pp.

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Monika HÖLZEL & Michael WAGREICH

Department of Geological Sciences, University of Vienna, UZA II - Althanstr. 14, 1090 Vienna, Austria, email: monika.hoelzel@univie.ac.at