EUG XI

Symposium OS04

Tectonics and Sedimentation

Convenors

Tom McCann
A. Saintot

OS04
Tectonics and Sedimentation

Sunday PM Session

OS04 : SUpm25 : G8
Evolution of the Southern Margin of the Donbass (Ukraine) from Devonian to Early Carboniferous Times

Tommy McCann (tmc@gfz-potsdam.de)[1], **Aline Saintot** (saia@geo.vu.nl)[2], **Alexander Alekseev** (aaleks@geol.msu.ru)[3], **Arjan Brem**[2], **Francoise Chalot-Prat** (chalot@crpg.cnrs-nancy.fr)[4], **Pavel Fokin** (fokin@geol.msu.ru)[3], **Timothy John** (timj@geo.vu.nl)[2], **Alexander Kitchka** (kitchka@casre.kiev.ua)[5], **Reinhard Sachsenhofer** (sachsenh@unileoben.ac.at)[6] & **EUROPROBE-INTAS Team**

[1] GeoForschungszentrum Potsdam, Telegrafenberg C127, D-14473 Potsdam, Germany
[2] VU Instituut voor Aardwetenschappen, De Boelelaan 1085, 1081 HV AMSTERDAM, The Netherlands
[3] Moscow State University, Russia
[4] CRPG, Boite Postale 20, 54501 Vandoeuvre-les-Nancy, France
[5] Institute of Geological Sciences, 55B Gonchar street, 01601 Kiev, Ukraine
[6] University of Leoben, Peter Tunner Str. 5, A-8700 Loeben, Austria

The Donbass Fold Belt-Karpinsky Swell region forms the inverted part of the intracratonic Dniepr-Donets Rift Basin and is, therefore, of key importance both for constraining the anomalous subsidence history and formation mechanism of the linked Dniepr-Donets-Donbass-Karpinsky-Peri-Caspian sedimentary basin system, and also for solving the puzzle of Late Palaeozoic palaeogeography along the southern part of the East European Craton. The Donbass Foldbelt (DF) is a 150 km wide region which extends 500 km from the eastern Ukraine to SW Russia.

The study area comprises a series of small half-graben basins which developed between the Vassilievka Fault, located within the Priazov Massif, to the south and the Yujni Fault, marking the southern boundary of the Styla Horst, to the north. These WNW-ESE-oriented faults delineate a region which, while marginal to the true DF, is of key importance for our understanding of the initial phases of basin evolution in the region. Palaeostress analysis recognising a NNE-SSW tensional trend under which these WNW-ESE-trending normal marginal faults developed. No evidence of oblique movement was recorded.

The combination of tectonic activity, sedimentation and relative sea-level variations in the southern Donbass region has resulted in the development of a complex facies mosaic. Following the deposition of a pre-rift Eifelian-Givetian clastic, mainly continental sequence, fault activity, leading to the initiation of a characteristic half graben tectono-sedimentary succession, commenced. The northerly Yujni Fault was the main graben-bounding fault, with activity along the Vassilievka Fault being more restricted. Both faults, however, played an important role in the generation and development of half grabens in the region. Initial rifting was accompanied by magmatic injection along fault zones with associated basalt-dominated extrusive activity leading to the formation of a chain of sub-aerial volcanoes. The lower part of the syn-rift succession is composed of continental clastics with intercalated volcaniclastic units. Rifting ceased during the Famennian and was followed by a period of tectonic quiescence which extended into the early Early Visean. Marine shelf carbonates and associated terrigeneous mudstones were deposited under relatively low energy conditions leading to the growth of a thick platform sequence. A relative sea-level fall, with possible associated basement uplift, in the late Early Visean led to sub-aerial exposure of the platform sequence and karst development synchronous with renewed effusive volcanism. The subsequent sea-level rise flooded the karstified surface with deposition of a fine-grained clastic, predominantly siliceous unit. This unit shows a variety of wet-sediment deformation features - including, slumping, folding and faulting - which we have interpreted as being related to rift reactivation in Early Visean times. Fault activity along the Yujni Fault led to a period of renewed tectonic instability in the region, producing an efficient slope on which the terrigenous clastic unit could slide.

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Alluvial Fan, Fan Delta, and Turbidite Facies Associations in a Tectonically Active Basin: The Miocene Köprü Basin (Isparta Angle, Southern Turkey)

Max Deynoux (mdeynoux@illite.u-strasbg.fr)[1], **Olivier Monod** (olivier.monod@univ-orleans.fr)[2], **Mustafa Karabyikoglu** (karabyik@web.mta.gov.tr)[3], **Attila Ciner** (aciner@hacettepe.edu.tr)[4], **Gianreto Manatschal** (manatschal@illite.u-strasbg.fr)[1], **Sevim Tuzcu** (sevim@web.mta.gov.tr)[3] & **Catherine Kuzucuoglu** (kuzucuoglu@netcourrier.com)[5]

[1] EOST - UMR 7517, 1, rue Blessig, Strasbourg, 67084, France
[2] ISTO, Université d'Orléans, 45067 - 0rléans, France
[3] MTA Institute, Geology Dept., 06520 - Ankara, Turkey
[4] Hacettepe University, Dept. Geological Engineering, 06532 - Ankara, Turkey
[5] IFEA, Nuru Ziya Sok. 22, 80072 - Beyoglu - Istanbul, Turkey

Sedimentation in the Miocene basins in the central area of the Isparta Angle (Alpine Taurus Chain) is strongly dependent upon preexisting structures and complex tectonic history from Late Cretaceous to Late Miocene (Akay et al 1985, Flecker et al., 1995).

The Köprü Basin forms an elongated N-S trough (65 km long, 5 to 25 km wide) opening and deepening southward. The Miocene infill rests unconformably on the Mesozoic para-autochthonous carbonate platform with an onlap geometry which is clearly visible on the western and northern borders of the basin. At the present day eastern limit of the basin, these deposits were folded and locally thrusted during the reactivation of the Kirkkavak Fault. The various conglomeratic facies which characterize the northern and western parts of the basin strongly contrast with the low energy and deeper facies which are widespread southwards and eastwards.

A progressive transition from alluvial fan to fan delta (with scattered patch-reefs), to debris flows, and finally to fine-grained turbidites can be observed over only a few tens of kilometers These rapid and well exposed changes in depositional settings provide data on the shape and evolution of the basin and allow the definition of several facies and facies associations which may serve as models for the sedimentary record in active tectonic settings.

Special attention is given to the distinction between subaerial or subaquatic conglomerates, which is usually a difficult problem with limited outcrops, although several authors have proposed various criteria (e.g. Nemec and Steel, 1984). The distinction relies on sorting, bedding, matrix content, nature and shape of the reworked material, bounding surfaces, and facies relationships. Another specific point concerns the origin and tectonic and/or climatic significance of thick (over a hundred meter) and widespread accumulations of polymict carbonate breccias. These breccias are either folded and intercalated with conglomerates along the Kirkkavak fault demonstrating a late Miocene tectonic activity in the northern part of the basin, or fill large-scale paleodepressions in the underlying carbonate platform suggesting that the present landscape is the remnant part of a highly contrasted Miocene palaeotopography.

Paleogeographic reconstructions are now possible owing to a clear distinction between continental and proximal or distal marine conglomeratic deposits, and emphasize the strong tectonic asymmetry of the basin. The prospect to modelise the sedimentological processes occuring in the Köprü Basin is a challenging opportunity to present a new model of basin filling in a tectonically active setting.

Akay U, Uyssal S, Poisson A, Cravatte J & Müller C, *Geol. Soc. Turkey Bull*, **28**, 105-119, (1985).
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Nemec W & Steel RJ, *Sedimentology of Gravels and Conglomerates, Can. Soc. Petr. Geol. Mem*, **10**, 1-31, (1984).

OS04 : SUpm27 : G8
Neogene Morphotectonics in the Köprü Basin (Isparta Angle, Southern Turkey)

Olivier Monod (olivier.monod@univ-orleans.fr)[1], **Gianreto Manatschal** (manatschal@illite.u-strasbg.fr)[2], **Max Deynoux**, **Attila Çiner**[3], **Mustafa Karabiykoglu**[4], **Sevim Tuzcu** & **Catherine Kuzucuoglu**[5]

[1] ISTO, Université d'Orleans, 45067 Orleans, France
[2] EOST, 1 rue Blessig, 67084 Strasbourg, France
[3] Hacettepe University, Dept of Geological Engineering, 06532 Ankara, Turkey
[4] MTA Institute, Geology Dept., 06520 Ankara, Turkey
[5] IFEA, Nuru Ziya Sok. 22 PK54, 80072 Beyoglu Istanbul, Turkey

The origin and significance of the three Miocene basins occupying the center of the 'Isparta angle' in the Taurus chain is controversial. A simple model put forward by Flecker et al. (1995) considered these basins (Aksu, Köprü and Manavgat) as parts of a foreland basin in front of the advancing Lycian nappes. However a closer examination of the Manavgat Basin (Karabyikoglu et al, 2000), has not shown facies migrations as expected for a foreland basin, but clear affinities with the Adana basin, 250 km farther east.

In contrast, the Köprü Basin exhibits conspicuous facies changes from north to south, reflecting active synsedimentary tectonics. Along its eastern border, the Kirkkavak Fault (KKF) was probably originated as a Late Eocene oblique wrench fault partitioning the thrusts in the Taurus chain. The normal offset of this fault created a high relief to the east, which was subsequently eroded as shown by conspicuous carbonate breccias (Langhian in part) interbedded within all the facies of the Köprü basin. However, in some places, these breccias obliterate the fault plane itself, suggesting that most of the relief was created before Langhian time. A later (Tortonian) E-W compressional event reactivated the KKF into westwards reverse faulting, as can be seen in the northern part of the basin (Incebel Pass).

If true, this tectonic framework implies that a high relief was built on the eastern side of the Isparta angle between upper Eocene and lower Miocene. Indeed, large fragments of a high surface have been recognised in the high karstic regions of the Taurus where no surface drainage presently exists. Several deep palaeo-valleys that incise this high surface are possibly remnants of the feeders that brought the early Miocene conglomerates, as requested by the origin of the transported materials.

Conversely, on its western side, the Köprü basin exhibits an uninterrupted succession, over 2000 m thick (Bozburun Dag) of onlapping deltaic conglomerates suggesting a strong subsidence in the center of the basin, where turbidites predominate.

In conclusion the setting of the Köprü basin cannot be interpreted as a part of a simple foreland basin but should instead be tectonically related to Miocene deformations responsible of the closure of the Isparta angle.

Flecker R, Robertson AHF, Poisson A & Müller C, *Terra Nova*, **7**, 221-232, (1995).
Karabyikoglu M, Çiner A, Monod O, Deynoux M, Tuzcu S & Örçen S, *Tectonics and Magmatism in Turkey, Geol. Soc.*, **Sp. Pub 173**, 271-294, (2000).

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'The History of the Hudson Bay – Constraints from 2D Subsidence Modelling'

Detlef Hanne (hanne@esc.cam.ac.uk), **Nicky White** & **Steve Jones**
University of Cambridge, Bullard Laboratories, Madingley Rise, Cambridge CB3 0EZ, Great britain

The geological history of the Hudson Bay Basin as one of the largest intracratonic sedimentary basins on Earth is puzzling.

The basin is characterised by a large negative free-air gravity anomaly and its center is filled mainly with sediments of Ordovician to Devonian age to about 1.5 km thickness. Normal faulting can be observed in the Ordovician and Silurian. There is some evidence for Mesozoic sediments in the adjacent Moose River Basin.

Here, we analysed the sedimentary record from the basin using the 1D and 2D Strain Rate Inversion Algorithm developed by N. White (1994) and P. Bellingham (1999), respectively. The 1D Strain Rate Inversion Model is well established in basin analysis. The recently developed 2D Strain Rate Inversion Model determines varying strain rates in time and space by minimizing the misfit bewteen the theoretical and observed subsidence of extensional basins. The model requires the sedimentary sequence and lithological and stratigrahical information. The output is then the strain rate distribution in time and space.

The results from the subsidence modelling show, that a minor rift-event took place in the Ordovician and Silurian. Rifting was accompanied by normal faulting, but not by volcanism. Afterwards, the basin was uplifted and eroded. The appearance of Cretaceous sediments in the Moose River Basin seem to indicate subsidence in the Mesozoic. These sediments were eroded, before the basin subsided again in the Neogene. The lower limit of the estimated eroded sediments ranges between 500 and 1000 meters.

Key words: Hudson Bay, Subsidence Modelling,

White, N., *Earth an Planetary Science Letters*, **122**, 351-371, (1994).
Bellingham. P., *Extension and Subsidence in One and Two Dimensions, North of 60 Degrees N, PhD thesis, University of Cambridge, UK*, 238pp., (1999).

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Growth Faulting and Hydrothermal Activity in Earth's Earliest Sedimentary Basins

Sjoukje T. De Vries (stdevries@geo.uu.nl) &
Wout Nijman (wnijman@geo.uu.nl)
Department of Sedimentology, Institute of Earth Sciences, Utrecht University, PO Box 80021, 3508 TA Utrecht, The Netherlands

In this study, relationships between growth faulting, volcanism and hydrothermal activity in a ~3.4 Ga old basin are investigated. Large-scale growth faults with a spacing of ~3.5 km, forming an array of more than 30 km, have been recognised in the upper Hooggenoeg Formation, Barberton Greenstone Belt, South Africa. At about 1.5-km depth, these listric normal faults converge into subhorizontal detachments in the mafic to ultramafic substrate of the basin. Large parts of the fault traces are obscured by tonalitic to dacitic igneous bodies.

The upper Hooggenoeg Formation consists of a sequence of komatiitic and pillow basalts, interbedded with thin chert beds of sedimentary origin, and intruded by large felsic igneous bodies. The sequence is capped by the Buck Ridge Chert (BRC) complex, a felsic volcano-sedimentary sequence divided into four units: (1) a volcano-sedimentary unit, (2) the coarsening upward - fining upward Lower BRC (a well banded and flow-banded chert), (3) an iron-oxide rich, locally brecciated zone overlain by (4) a thin, well banded, evenly laminated to crossbedded chert/sandstone interval (Upper BRC). The sequence is interpreted to have formed in a felsic volcanic environment, showing a major phase of regression, followed by a transgression.

Felsic intrusion below the BRC complex occurred toward a level only a few hundreds of metres below the sediment-water interface, accounting for a locally high thermal gradient. From this felsic body, large black chert veins ascend into the hanging-wall block of one of the normal faults, and terminate upon reaching unit 2. At such sites, interpreted to represent hydrothermal vents and related plumbing systems, the cherts contain silica sinters with microbial remains and crystal palisades (nahcolite, according to Lowe and Worrell, 1999). Since some of these crystals seem to originate from tiny (chert) veins, and the crystal palisades show crosscutting relationships with the bedding, they might be hydrothermal in origin rather than evaporitic.

Stratigraphically directly above the major black chert vein system, a funnel-shaped breccia occurs. This might be interpreted as a hydrothermal eruption breccia, representing the surface expression of the hydrothermal system. It consists of fragments of the underlying units, in an extremely Fe-oxide-rich matrix. The increasing iron content in units 2 and 3, together with the occurrence of (possibly syndepositional) liesegang rings, indicates that at maximum regression the BRC may have been subaerial. This interpretation is controversial however, since this would require (locally) oxidising atmospheric conditions, whereas the Early Archaean atmosphere is generally believed to have been reducing.

Similar relationships between growth faults and vein systems have been found in greenstone belts of the Pilbara (Western Australia): in the North Pole area large black chert vein systems obviously ascend from the growth faults in radiating patterns towards the banded cherts (Nijman et al., 1999).

Lowe DR & Worrell GF, *Geological Society of America Special Paper*, **329**, 167-188, (1999).
Nijman W, De Bruijne CH & Valkering ME, *Precambrian Research*, **95**, 247-274, (1999).

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Relay Ramps and Fault Linkage along the Early Coffee Soil Fault System, Danish Central Graben

Lars Hjelm (lars.hjelm@geo.aau.dk)[1],
Ole R. Clausen[1], **Robert Hunsdale**[2],
John A. Korstgård[1] & **Kåre R. Vagle**[3]
[1] Geo. inst., Aarhus Uni., DK-8000 Aarhus C, Denmark
[2] Phillips Petroleum Company Norway, Postboks 220, 4098 Tananger, Norway
[3] Phillips Petroleum Company Norway, Postboks 220, 4098 Tananger, Norway

The structurally complex Coffee Soil Fault System (CSFS) forms the eastern boundary of the Danish Central Graben. This study aims to unravel the structural evolution of the fault system, in order to understand the interaction between subsidence history and sedimentation in the associated Sogne Basin and Tail End Graben (TEG).

The CSFS is presently characterised by a broad zone of westward dipping normal faults, whose orientation varies from WNW-ESE in the south to N-S in the northern part of the Danish Central Graben. The maximum offset observed along the CSFS today is 7 km. Activity along the CSFS dates back to Late Carboniferous-Early Permian times with the formation of large east-dipping fault blocks. Major rejuvenation took place in the Late Jurassic, followed by basin inversion and localised inversion along the major faults in the Cretaceous and Paleogene. Subsidence and deposition was locally influenced by movement of the Zechstein Salt throughout the Mesozoic and Cenozoic.

Jurassic rifting along the CSFS started in the Late Aalenian - Early Bajocian with the development of several N-S striking west-dipping en Èchelon normal faults. These newly formed Jurassic faults were left stepping in the southern part of the Tail End Graben, whereas they were right stepping in the northern part. The faults were probably soft-linked by relay-ramps before being hard linked and bridged by transfer faults. Hard linkage and continued faulting on the CSFS generated the present complex architecture.

The footwall of the CSFS was heavily eroded during the Jurassic and Lower Cretaceous. Sediments produced along the footwall scarp may only have entered the Central Graben in larger quantities via relay-ramps. The main focus of the seismic mapping and structural analysis performed in this study is to elucidate on the potential site of such relay zones and predict dispersal patterns of Jurassic coarse-grained clastics in to an otherwise sediment-starved TEG.

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Structural and Sedimentological Evolution of the Ruhr Basin (NW-Germany) – Modelling and Simulation of a Palaeozoic Foreland Basin

M. Peter Suess (suess@uni-tuebingen.de)[1],
Kasper Fischer (kfischer@geo.uni-jena.de)[2],
Guenter Drozdzewski (drozdzewski@gla.nrw.de)[3],
Thomas Jahr (jahr@geo.uni-jena.de)[2],
Gerhard Jentzsch (jentzsch@geo.uni-jena.de)[2] &
Andreas Schaefer (schaefer@uni-bonn.de)[4]
[1] Geologisches Institut, Universitaet Tuebingen, Sigwart-Strasse 10, 72076 Tuebingen, Deutschland
[2] Institut fuer Geowissenschaften, Burgweg 11, 07749 Jena, Deutschland
[3] Geologisches Landesamt NRW, de-Greiff-Strasse 195, 47803 Krefeld, Deutschland
[4] Geologisches Institut, Universitaet Bonn, Nussallee 8, 53115 Bonn, Deutschland

Orbital forced sea-level changes in the Carboniferous induced worldwide observed sedimentological patterns. In our example, the Ruhr Basin (NW-Germany) developed as a terminal foreland basin in front of the Variscan orogen during the Carboniferous. Stratigraphic modelling provided a compilation of a high-resolution time scale for use in its basin-fill. Stratigraphic correlations of wells from coal mining led to an estimation of the accumulation of sediments. Calculated subsidence curves, cross-sections, and thickness maps revealed a moving structural high within the Ruhr Basin during the deposition of the strata, due to the approaching orogen. Quantitative 2D- and 3D-numerical simulations, using finite element and finite difference techniques, evaluated alternative geodynamic models of this geomorphologic element. The simulations incorporated loading effects and stresses of the advancing plates as well as long term erosional/depositional dynamics of the evolving orogenic wedge and the basin. The applied techniques faciliated to precise a balance between the denudation of the orogen and the accumulation of sediments in the basin. The resulting models explain depositional geometries and related stratigraphic surfaces, that generally form in foreland basins.

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A Neoproterozoic Orogen at the Present-Day SW Margin of the East European Craton

Andrzej Zelazniewicz (pansudet@pwr.wroc.pl)[1],
Antoneta Seghedi (antoneta@igr.ro)[2],
Monika Jachowicz (roig@pigog.com.pl)[3],
Wojciech Bobinski (wbob@pigod.wroc.pl)[3],
Zbigniew Bula (roig@pigog.com.pl)[3] &
Stefan Cwojdzinski (scwo@pigod.wroc.pl)[3]
[1] Instytut Nauk Geologicznych PAN, Podwale 75, PL-50449 Wroclaw, Poland
[2] Geological Institute of Romania, 1 Caransebes, RO-78344 Bucharest 32, Romania
[3] Panstwowy Instytut Geologiczny Oddzial G-rnoslaski, Kr-lowej Jadwigi 1, PL-41200 Sosnowiec, Poland

An earlier recognition of fragments of a Neoproterozoic orogen in southern Poland, encroaching the East European Craton (Zelaniewicz, 1998), is strengthened by new data from boreholes in Maeopolska and Upper Silesia, along with a comparison with the Vendian Histria Fm. in Dobrogea, Romania. Acritarch studies proved Vendian age of the Maeopolska flysch (Moryc & Jachowicz, 2000). An U-Pb zircon age of 2.7 Ga (Bylina et al., 2000) shows that the underlying basement contains rocks corresponding with parts of the EEC. Fragments of the c. 590-540 Ma inner part of the orogen, now concealed under the Phanerozoic, occur in Brunovistu-li-cum (the Brno and Upper Silesia massifs). Southern Poland apparently embraces section of the Precambrian crust consisting of Neoprotero-zoic orogenic core, fore-land, and older cratonic basement. A provenance analysis shows that the Maeopolska flysch was derived from a recycled orogen. It was sourced from an active continental margin with some volcanic arc component and from tectonically induced intrabasinal highs. The flysch sequence was brought into large-scale inclined folds. In the more internal part of the sequence the folding was accompanied by subvertical axial planar crenulation cleavage and regional metamorphism at temperatures of 100-300°C (illite crystallinity, S. Kowalska, pers. comm.). Both the deformation and metamorphism show W-E oriented zonation, with intensity decreasing toward the north, which points to a northward polarization of the orogenic strain and a southern location of the inner part of the orogen. These observations allow us to infer that the major folds and thrust in the Maeopolska flysch also strike W-E with northern vergence; thus they are oblique to the NW-trending margin of the EEC.

The Vendian Maeopolska flysch known from subcrops is similar to the Vendian flysch of the Histria Fm., which outcrops in Central Dobrogea. The latter also developed on an old conti-nental crust, in a basin sourced from the southerly located active continental margin, dominated by a volcanic arc, as shown by the heavy mineral spectrum. The continental source was likely akin to Archean and Proterozoic rocks in S Dobrogea, including a characteristic banded iron-forma-tion (BIF). The nearest BIF occurs in the Ukrainian Shield, which may suggest basement connection to the EEC. The Histria Fm. is also involved in the W-trending and N-verging folds, with subvertical axial planar cleavage, accompanied by weak metamorphism.

Taking into account all the similarities in age, sedimentology, mineralogy, tectonics and regional settings, the corollary is that in Maeopolska, Upper Silesia and in Central Dobrogea there are crustal fragments, which, although later displaced, once belonged to the same Neoproterozoic orogen, in particular to its foreland part, with the W-E structural grain. It obliquely collided with the EEC along its present-day SW margin and has remained next to it during the Phanerozoic.

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Zelazniewicz A, *Acta Universitatis Carolinae, Geologica*, **42**, 509-515, (1998).

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Tectonic and Sedimentation in the Tertiary Piemonte Basin (Alpine Domain, Northwest Italy)

Barbara Carrapa (carb@geo.vu.nl)[1],
Giovanni Bertotti (bert@geo.vu.nl)[1],
Jan Wijbrans (wijj@geo.vu.nl)[1] &
Wout Krijgsman (krijgsma@geo.uu.nl)[2]
[1] Vrije Universiteit, Dept.of Earth Sciences, De Boelelaan 1085, 1081 HV Amsterdam, The netherlands
[2] Utrecht University, Faculty of Earth Sciences, Budapestlaan 17,3584 CD Utrecht, The Netherlands

The Tertiary Piemonte basin (TPB) is situated at the boundary between the Alpine and the Appenine chain sealing the deep and shallow structures related to them. The evolution of subsidence in the TPB can be traced from the beginning of Oligocene time in a period of important movements within the western Mediterranean area like the continental collision between Adria and Europe and the opening of the Provencal-Ligurian basin.

The basin history (subsidence and sedimentation) begins in the late Eocene-early Oligocene with conglomeratic/sandy facies marking the transgression on both Alpine and Ligurian units. Subsidence analysis has been conducted in the basin to investigate larger scale tectonic mechanisms. Preliminary curves have been constructed and two main periods of subsidence have been detected. The first one is concomitant with the initial formation of the basin during Oligocene time and the other, stronger then the previous one, in middle Miocene (Burdigalian-Langhian).

In the same period of strong subsidence during the Miocene, larger scale reorganization is taking place in the basin. From a sedimentological point of view turbidity bodies became more tabular with characteristics common to the whole basin. Currents became more homogeneous with directions from W-WNW towards E-ESE from upper Langhian time on (Gnaccolini M & Rossi PM, 1994). Concurrently data from ^{40}Ar/^{39}Ar geochronology on detrital white micas suggest that a western alpine source area began to contribute to the sediment budget from Burdigalian-Langhian time on.

Outcrop scale structures such as folds and faults have been analyzed to determine stress and strain regimes during and following subsidence. Two contractional regimes have been determined, one with direction of shortening NE-SW and the other NW-SE. The shortening with axis NE-SW was active during Langhian-Tortonian time but previous studies, on the southern area, show evidence of shortening with the same orientation active during Oligocene time (Mioglia fold). Two extensional stages have also been detected, however with poorly constrained absolute ages. The directions of deformation have been confirmed from magnetic susceptibility anisotropy data. In general, both contractional and extensional structures are unable to explain the observed magnitude of the subsidence.

Gnaccolini M & Rossi PM, *Atti Tic. Sc. Terra*, **37**, 3-15, (1994).

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The Québec Promontory Nappe: From Syntectonic Flexural Extension to Taconian Overthrusting

Thomas Gayot (thogayot@yahoo.fr)[1],
Donna Kirkwood (dkirkwoo@ggl.ulaval.ca)[2] &
Michel Malo (mmalo@inrs.uquebec.ca)[3]
[1] 7 rue Sidonie Jacolin Grenoble, 38000, France
[2] Université Laval; département de géologie et de génie géologique, Ste-Foy, (Qc) G1V 7P4, Canada
[3] INRS, 880 Chemin Ste-Foy, Québec (Qc), G1S 2L2, Canada

The Québec Promontory Nappe (QPN) belongs to the external Humber Zone of the Canadian Appalachians. It is limited, to the north, by the Logan's Line wich represents the western boundary of the Québec Appalachians allochtonous. The QPN, the lowest structural unit of the allochtonous terrains, contains the younger rocks unit (Upper Ordovician) and is overthrust by the Pointe the Lévy slice, to the southeast, and by the Chaudière Nappe, to the south.

The QPN consists of the Lower Caradocian rocks of the Citadelle Formation (CF). Two dictinct facies are recognised within the CF: rocks of 'outer shelf facies (o.s.f.)'; and roks of 'mélange facies (m.f.)'. Contacts between these two facies are three-fold:
• a normal stratigraphic contact, where representative beds of both facies interstratified, demonstrating that both facies are contemporary;
• a sharp contact displaying channel structures;
• a normal fault contact.
These faults induce trenches filled by rocks of 'm.f.'. Blocks of 'o.s.f.' have been also shedded in these filling zones. The characteristic plastic deformation of these blocks shows that they were still soft suggesting synsedimentary normal-faulting.

Several structural elements have been observed within rocks of the QPN. They are:
• syn-sedimentary normal faults and extension fractures, spacially associated with rocks of 'm.f.';
• NNE-SSW trending major westerly verging compressives structures such as F1 folds, S1 cleavage, and thrust faults.
• WNW-ESE trending northerly verging compressives structures such as F2 folds, S2 cleavage.

Cross-cutting relationships helped deduce the chronological development of the structures within the QPN and propose the following tectonic evolution:
• An extensional event (DI) during which rocks of the CF were deposited on a tectonicaly unstable outer shelf in a foreland basin setting during the Taconian orogeny (Carodocian). This event is interpreted as the collapse of the outer shelf and attributed to lithospheric flexure induced by thrust loading. Collapse of the internal shelf occurred later during Caradoc to Early Ashgill.
• A compressional event (DII) resulting in folding and thrusting of the CF over the autochthonous shelf during the Ashgill.
• A late compressional event (DIII) attributed to thrusting of the Chaudière Nappe over the QPN inducing local folding and cleavage development (F2 and S2) in the southern part of the nappe. This event is not well constrained and could be related to a later phase of the Taconian Orogeny (Late Ordovician-Early Silurian) or to the mid-Devonian Acadian orogeny.

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OS04 : SUpm37 : G8

Geometry and Timing of Cretaceous to Eocene Compresional Structures on the Northern Flank of the Eastern Pyrenées

Frédéric Chistophoul (christop@cict.fr),
Jean Claude Soula, **Brice Elibana**,
Brusset Stéphane & **Joachim Déramond**
Dynamique des Bassins, 38 Rue des 36 ponts, 31400 Toulouse, France

During Upper Cretaceous and Eocene time, the Sub-Pyrenean zone was progressively integrated into the wedge-top depozone of the foreland basin system (DeCelles et Giles, 1996) of the Northern Pyrenees. The geometry and structural evolution of the fold and thrust structures abd related depocentres have been analysed by mean of the construction and sequential restauration of balanced cross-section in the eastern part of the range. In the Paleocene and Eocene units, which were directly deposited upon the paleozoic basement was located in front of a basement involved ramp anticline. In the Upper Cretaceous units, the deposition of and the location of the depocentres were controlled by a thrust- propagation fold (Suppe and Medwedeff, 1990) evolving into a CAS structure (Cheveuchement, Anticlinal , Synclinal, Déramond et al., 1993) with the successive development of 2 or 3 overstepping thrust branches. This structures is now overridden by thrust units including only Triassic, Jurassic and lower to middle Cretaceous strata of the North Pyrenean Zone that strongly suggests that only the upper décollement level was active. All these structures are branched onto two major décollements located one within the Middle Ordovician slates and the other within the Upper Triassic evaporates. At the North Pyrenean- Sub-Pyrenean boundary, the upper décollement is inferred to have joined the lower because of the extensional transcurrent deformation at the origin of the Mid-Cretaceous 'Flysch' Basin of the North Pyrenean Zone. The following sequence of events is then proposed: 1)- After the extensional-transcurrent deformation of the Albo-Cenomanian, compressional deformation have occur first since the end of Cenomanian in the southern units where a thrust propagation fold evolving into a CAS controlled de deposition of turonian to Campanian turbidites (and the location of the depocentre). To the East, development of the CAS is accompanied by the positive inversion of the Mid-Cretaceous basins bounding fault. 2)- Since late Cretaceous and during the Paleocene and during Eocene times, a basement involved ramp anticline formed in the northern area and controlled the deposition of the Paleocene and Eocene units. 3)- Out of sequence thrusting occurred in the southern area with an overstep propagation as a result of the growth of the faults involved in the CAS and of the positive inversion of the pre-existing Albo-Cenomanian extensive-transcurrent faults not yet inverted.

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OS04 : SUpm38 : G8

Can Diapirism Explain Salt Anticlines?

Boris Kaus (kaus@erdw.ethz.ch) &
Yuri Podladchikov
Geologisches Institut, ETH-Zurich, Sonnegstrasse 5, CH-8092 Zurich, Switzerland

The driving mechanisms of salt tectonics have been heavily debated over the last 15 years. There are two main views: (1) salt tectonics is controlled by tectonic forces and brittle deformation of the overlying sediments and (2) salt tectonics is mainly driven by the density difference between the salt and the overlying sediments (diapirism). Observed salt structures (for example in Northern Germany) vary in geometrical shape from anticlinal (2D) to curved wall-like and finger-like (3D). Is it possible to explain the formation of all these structures with only a single mechanism? In order to answer this question, we developed a three-dimensional numerical model to study salt diapirism. The model includes geological relevant parameters, such as erosion and deposition, depth-dependent properties of the overburden and differential loading. It is shown that curved walls and 3D structures develop spontaneously out of an initially horizontal salt layer that is perturbed with some random noise. If the initial salt layer, on the other hand, has a 2D perturbation at the salt-sediment interface a salt anticline may develop. A systematic study of different initial 2D perturbations shows that a step-like perturbation is the most efficient way to create such an anticline. This perturbation could for example be caused by a fault cutting the salt-sediment interface. A comparison of the modeled data with natural examples shows a good agreement. The simulations thus demonstrate that it is indeed possible to explain the whole range of observed salt structures with only a diapiric ascent mechanism. The main controlling factor on the geometry and distribution of these structures is thus the initial spatial distribution of salt. Ascent rates for a diapiric mechanism vary several orders of magnitude and are largely dependent on the rheology of the salt and overlying sediments and the erosion rates above a developing salt dome.

Sunday PO Session

OS04 : SUpo01 : PO

New Geological Aspects of the Base of the Naukluft-Nappe-Complex, Central Namibia

Jeannine Meinhardt-Degen (rotwasser@yahoo.de), **René von der Heyde** (vonderheyde@yahoo.de), **Susanne Schmid** (susanne.schmid@student.uni-halle.de), **Jens Schwenke** (jens.schwenke@student.uni-halle.de) & **Gregor Borg** (borg@geologie.uni-halle.de)
Department of Geological Sciences, Martin-Luther-University Halle-Wittenberg, Domstrasse 5, 06108 Halle/Saale, Germany

The studied area is located 120 km south-west of Windhoek at the root of the Naukluft-Nappe-Complex in Central Namibia. The geological units of the area comprise Eburnian (Middle Proterozoic), Kibaran (Late Middle Proterozoic) and Damaran (Late Proterozoic to Cambrian) assemblages separated by at least two major unconformities. The oldest rock type is the highly deformed Piksteel Granodiorit Suite (Eburnian). This suite consists of an assemblage of plutonic rocks with a wide range of compositions from granites to gabbros. The metamorphic grade of these rocks has reached lower amphibolite facies. The present study focussed on the Piksteel Granodiorit Suite and the unconformably overlying Sinclair Sequence (Kibaran). The Sinclair Sequence and equivalents occur predominantly in Namibia and Botswana and represents a stage of failed rifting and bimodal volcanism and predominantly clastic. Sinclair Sequence equivalents within the study area are locally named Nauzerus Group and are dominated by the Grauwater Formation with high-and low-energy clastic sediments (with minor tuffs) and predominantly felsic volcanics of the Nückopf Formation. The Nückopf Formation comprises mainly porphyries of subvolcanic to extrusive origin. An absolute age of 1225 ±5 Ma has been determined by U/Pb zircon dating by Schneider (pers. commun.). Sills of basaltic composition and several generations of mafic and felsic dykes are abundant both in Sinclair and pre-Sinclair rocks. At several localities mafic dykes crosscut the Piksteel granodiorite and its foliation but not the overlying Sinclair sediments, thus predating the Sinclair age of 1225 Ma. The Sinclair rocks are unconformably overlain by clastic sediments and marbles of the Nama Group (Cambrian). A dolomitic sole thrust marks the boundary between the Nama Group and the allochthone of the overlying Naukluft-Nappe-Complex. Both, Piksteel Granodiorit Suite and Sinclair Sequence were metamorphosed to lower Greenschist facies grade and all units within the area (including the Nama-Group and Naukluft-Nappe-Complex) have been deformed by the Damaran Orogeny. The study has shown that previously proposed lithostratigraphic and chronostratigraphic subdivisions for this area may have been oversimplified. Lateral contacts between different units of the Sinclair Sequence facies changes, but commonly due to tectonic contacts. The spatial and genetic relationship between the Piksteel Suite and the Sinclair Sequence has been well-established whereas the relationships within the Sinclair Sequence (Grauwater Fm., Lower Nückopf Fm. and Upper Nückopf Fm.) require further investigations.

OS04 : SUpo02 : PO

The Tectonic and Sedimentation in the Eastern External Zone of Betic Cordilleras Influence of the Opening of the North Atlantic Ocean?

Elena Fernandez-Fernandez (emferfer@inicia.es)[1], **Antonio Jabaloy** (jabaloy@ugr.es)[2] & **Francisco Gonzalez-Lodeiro** (lodeiro@ugr.es)[2]
[1] Arriola, 4, 21/4 C, 18001 Granada, Spain
[2] Dpto. Geodinamica, Univ. Granada, 18071 Granada, Spain

In the Vélez Blanco region (Subbetic Zone, eastern Betic Cordillera) tow sets of Mesozoic high angle faults can be observed. One set of these normal faults have N70ºE to N114ºE strikes and deeps mainly toward the south. The other set has N135ºE to N200ºE strikes and deeps to the east and west. Both sets of faults generate half-grabens, that were filled with wedge shaped formations deposited during Late Jurassic to Lower Cretaceous times. The great thickness of these formations are found close to the fault surfaces and in the opposite side of the half-graben every younger formation on-laps over the older one, indicating the progressive tilting of the hanging-walls during the deposit of the rocks. Most of the filling of the basins was generated by the erosion of the fault scarp. The biggest basins are related with the E-W fault. In some of these basins there are 1500 to 2000 meters thickness of sedimentary filling deposits, while the N-S basins are very small only few meters of thickness. The Dogger rocks, that predate the faulting stage, are shallow marine oolitic sedimentary rocks. The Middle Cretaceous formation, that is the last one fault related, has evidences of deposits closer C.C.D. (Lopez-Galindo, 1986). In the Albian Cenomanian times the C.C.D. depth was located near -3200 to -3500 meters in the Central North Atlantic (Van Andel, 1975). These evidences shows that the normal fault was related with a very important thinning of the continental crust. Paleomagnetics studies in the area demonstrate the existence of clockwise rotation with vertical axes in Miocene times. These rotations may reach 125º (Allerton et al., 1993). Restoring the fault strike of the original orientation shows that the main basins have really NNE-SSW trends while the small one haas a WSW-ENE strike. This extensional stage happens in the same time than the rifting of Iberian and North America, the opening of the Biscay gulf and the aborted rifting of the Iberian system.

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OS04 : SUpo03 : PO

The Evolution of the Oriental Margin of the Moltrasio Limestone Basin from the Late Norian to the Early Lias

Cecilia Pasquini (geo@unipv.it) & **PierLuigi Vercesi** (vercesi@unipv.it)
Dipartimento di Scienze della Terra, Università di Pavia, Via Ferrata 1, 27100 Pavia, Italy

The recognition of the stratigraphic succession in the Como Lake South-East zone (from the Principal Dolomite to the Sogno Formation) and the analysis of its stratigraphic and structural relationships allowed to delineate the paleogeography of the Moltrasio Limestone depositional basin. Moreover, it permitted to describe the drowning of the Late Triassic to the Early Lias carbonate platform, on wich Sedrina Limestone and Moltrasio limestone settled. The sedimentological analysis and the mapping of slumps, debris flows and megabreccias in the Sedrina Limestone and Moltrasio Limestone has allowed to outline the form of the depositional basin and to highlight the role of the Jurassic normal faults. The drowning phase is preceded by a period of emersion of the Principal Dolomite and Conchodon Dolomite platform, proved by several exposure surfaces. Above these formations settled the Moltrasio Limestone, rich in slumps, magabreccias and erosional scours. These structures show, in the general context of platform sinking, an abrupt phase of evolution, with a diffuse slope instability. In the northern zone (Mt. Oriolo) is possible to find evident marks of the synsedimentary faults activation. By these faults the layers are wedge-shaped. The paleogeography of the Moltrasio Limestone sedimentation basin in the Early Lias is very complex. In this context some characteristic elements emerge: i) a structural high zone; ii) an intraplatform basin; iii) the Moltrasio Limestone basin. i) The structural high zone is located in southern zone (Mt. Corni di Canzo, Mt. Cornizzolo, Mt. Rai) and was the substratum on which the Moltrasio Limestone settled in on-lap. The small thickness of Zu Limestone, Conchodon Dolomite and Sedrina Limestone proves that the area, already structural high during the Early Lias, mantained this structural position in also later periods. ii) The Ravella valley intraplatform basin lies in a inner zone of the structural high and borders on W-SW the deep basin s.s. The sedimentary succession is condensed but complete, with small slumps and thin laminations indicating a tectonic less intense with respect to the one found by the deep basin or in its margins. iii) During the Early Lias, the Moltrasio Limestone basin in appears as a ramp that, though cut by slopes and flats, reached high depth. The tectonic slopes are proved by direct contacts between the Moltrasio Limestone and the Principal Dolomite or Zu Limestone. Near the slope, a very high subsidence rates, associated to great sediments amount, triggered big submarine slumps (Mt. Cornizzolo, Mt. Corni di Canzo).

OS04 : SUpo04 : PO

Denizli Episodic Graben: Its Evolution, Age, Slip and Seismicity

Ali Kocyigit (akoc@metu.edu.tr)
Middle East Technical University, Department of Geological Engineering, Tectonic Research Unit, TR-06531, Ankara-turkey

Denizli Graben is one of key structures of the continental extensional neotectonic regime in west Turkey. It is located at the eastern converging tips of the Gediz, Kucuk Menderes and the Buyuk Menderes grabens. The Denizli graben is 7 - 28 km wide, 62 km long and actively growing depression, bounded by a series of oblique-slip normal faults displaying step-like pattern. Major graben consists of, from W to E, four segments of dissimilar size and orientation: (1) NW-trending Buldan-Pamukkale segment that comprises main bulk of the graben, (2) E-W trending Honaz segment, (3) NE-trending Kocabas segment, and (4) again E-W trending Kaklik segment. Denizli graben evolved at two stages: (1) early-middle Miocene stage and (2) Plio-Quaternary stage. These two stages were interrupted by an intervening short-term compressional phase. This episodic evolution of the Denizli graben is indicated by: (a) two basin infills superimposed each other, (b) deformation patterns of basin infills where older fill is folded, but younger fill is nearly flat-lying, and (c) angular unconformity between lower-middle Miocene older infill and Plio-Quaternary younger infill. The first stage graben is wider than the second stage graben. It has been cut and dissected into several small-scale horsts and grabens during the second-phase of graben formation (extensional neotectonic period). Throw amount accumulated along the graben-bounding faults since Early Miocene is more than 0.5 km. Many of graben-bounding faults are active. This is indicated by: (1) morphotectonic criteria, such as fault-parallel hot water springs, travertine occurrences, hanging valleys, offset drainage system and their beds carved deeply into ground, (2) fresh slip-planes and slickenlines, and (3) both historical and recent seismic activities. Two ancient settlements, Hierapolis and Laodikeia, located in the Denizli graben were heavily devastated and collapsed by historical earthquakes. In the same way, city of Denizli and a number of towns and villages were damaged by 19 earthquakes with magnitudes of 4.1 and 5.7 occurred in the 19th century. A more recent seismic activity started to occur on 2000 April 21, and this is still lasting with very short time quiet periods for seven months. More than 400 seismic events with magnitude ranging from 2 to 5.2 were recorded. Consequently, it is not yet understood that these seismic activities are foreshocks for a near future large earthquake or not?

OS04 : SUpo05 : PO

Dynamic Implications of Minor Cenozoic Faults at the Brage Horst, Northern Norwegian North Sea

Ole Rønø Clausen (geolorc@geo.aau.dk), **Lise Kristensen** & **John A. Korstgård**
Geologisk Institut, Aarhus Universitet, 8000 Århus C, Denmark

Minor intra formational faults in the Cenozoic succession have been mapped using 3-D seismic data. Structural analysis involving structural reconstruction and orientation analysis was performed in order to unravel the factors controlling the generation and distribution of the minor faults.

The study area covers approx. 180 km^2 and is situated in the Norwegian sector above the Brage Horst, which evolved during two major rifting episodes. During Permo-Triassic extension the Brage East Fault, the future eastern boundary fault of the Brage Horst, was created as the western boundary fault of the interior full graben of the N-S trending Permo-Triassic rift system. During the next major rift phase in the Middle-Late Jurassic the rift axis moved to the west and the Brage Fault, which became the western boundary of the Brage Horst, was formed as a west-dipping fault on the foorwall of the Viking Graben. Movements along the faults defining the horst continued into the Early Cretaceous. The Horst itself was eroded during the late Middle Jurassic causing the removal of the Brent Group and only thin Upper Jurassic sediments cover the horst.

The pre-Oligocene Cenozoic sediments are dominated by clays with sandy and silty intervals. The sediments became more coarse-grained during the Oligocene, but clay dominated intervals prevail. Ductile deformation of the lower Oligocene succession created clay pillows and ridges, which are pronounced in the studied area.

The analysis shows that faulting probably took place during the early and middle Miocene. The faults are generally individual blind faults, and do not constitute a coherent mesh (i.e. the faults are not polygonal). The densities of faults vary across the study area and 3 directions dominate: NNE-SSW, NNW-SSE, and NE-SW. Our fault orientation analysis shows that the faults are related to deformation of the succession due to reactivation of underlying Mesozoic faults, clay diapirism and gravitational gliding due to regional Cenozoic subsidence focused west of the study area.

Overpressure seems only to have affected the deformation by enhancing the ductile deformation of the Lower Oligocene clays, which generated the clay pillows and clay ridges.

OS04 : SUpo06 : PO

Basement Structure in the Danish North Sea

Magdalena Scheck (leni@gfz-potsdam.de)[1], **Hans Thybo** (thybo@geo.geol.ku.dk)[2], **Tanni Abramovitz** (tanni@geo.geol.ku.dk)[2] & **Alexander Lassen** (al@geo.geol.ku.dk)[2]
[1] GFZ Potsdam, Telegrafenberg C427, 14473 Potsdam, Germany
[2] Geological Institute, Oster Voldgade 10, DK-1350 Copenhagen K, Denmark

Seismic reflection data of the Danish North Sea are re-interpreted to map the structure of the Paleozoic basement in the area of the deep seismic Mona Lisa lines. The study area comprises the southern part of the Horn Graben and the East North Sea High to the eastern shoulder of the Danish Central Graben. Main goals of the study are to analyse the structural setting of the Caledonian Deformation Front, which is crossing the area of investigation in the southern part according to radiometric age data (Frost et al., 1981) and to differentiate between Mesozoic and Paleozoic structures on the basement level. We present a Two-Way-Traveltime- map of the near-basement horizon and several interpreted seismic sections revealing that two main normal fault systems control the topography of the basement: (1) the northerly trending Mesozoic faults of the Horn Graben and the Central Graben intersect with (2) an older system of Paleozoic faults which are oriented subperpendicular to the Mesozoic system. The Paleozoic normal faults terminate at the Base Rotliegend unconformity and delineate several small grabens filled with Lower Paleozoic sediments. In the southern part of the study area, where the Caledonian Deformation Front is supposed to be located, we find only a narrow E-W striking zone with indications for compressive deformation in the Lower Paleozoic. This could indicate that the collision between Baltica and the microcontinent Avalonia was characterized by an oblique geometry and occurred under a transpressive stress regime.

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OS04 : SUpo07 : PO

Geometry and Development of Cenozoic Small Scale Faults in the Northern Danish Central Graben

Thomas Engholm Jacobsen (engholm@geo.aau.dk)[1], **Ole Rønø Clausen**, **John A. Korstgård** & **Poul-Henrik Larsen**[2]
[1] Geologisk Institut, Aarhus Universitet, 8000 Århus C, Denmark
[2] Maersk Oil & Gas, Esplanaden 50, 1263 København K, Denmark

The Danish Central Graben, mainly Mesozoic in age, was also the centre of the Cenozoic subsidence and deposition, and more than 3000 meters of siliciclastic sediments were deposited. The Paleocene and Eocene successions are dominated by clay deposits, whereas the Oligocene and younger sediments become coarser (silt and sand interbedded with clay). The rate of sedimentation increases during the Cenozoic, and the sediments below the Mid Miocene Unconformity in the Central Graben area, generally have excess fluid pressure.

The Cenozoic is generally regarded as a tectonically very quiet period, as far as the major graben generating faults are concerned. However, the Cenozoic succession is transected by a large number of minor faults (80 - 150 meters offset), which have been observed on 2-D seismic sections for years. In this study the minor faults have been mapped at different levels in the Eocene to Mid Miocene succession using 3-D seismic data in order to unravel the fault geometry, the relations to underlying structures and to suggest a model for the generation of the faults.

The faults are vertically confined to a number of stratigraphically constrained intervals that are intensely faulted, and the faults sole out into ductile layers. The lowermost faulted interval on which we focus here occur in Eocene sediments. At a first glance the faults constitute a polygonal network in map view. However, our detailed analysis shows that not all faults are laterally interconnected, and relay zones, ramps etc. are observed. The faults in the Eocene succession above the major tectonic feature in the area, the NNW trending Gert Ridge, dip towards the axis of the ridge, thereby generating a keystone structure. The dip of the minor faults towards the Gert Ridge is pronounced along the strike of the ridge although the polygonal pattern persists across the Gert Ridge.

The occurrence of the faults may reflect deformation due to differential subsidence, or escape of excess fluid pressure, or be the result of synaeresis. The polygonal pattern of the faults definitely indicates that the presence of excess fluid pressure played a major role, but the preferred orientation of the dip of the faults along the flanks of the Gert Ridge also shows that deformation due to differential subsidence was important. We thus suggest that the excess fluid pressure facilitates the generation of faults that reflect the strain imposed onto the Eocene sediments by differential subsidence across the Gert Ridge.

OS04 : SUpo08 : PO

Alluvial-Tectonic Relationships in a Foreland Setting: The Example of the Montagne Sainte Victoire (Provence)

Sophie Leleu, **Jean François Ghienne** & **Gianreto Manatschal**
EOST - CGS, UMR 7517, 1, rue Blessig, 67084 Strasbourg, France

Upper Cretaceous/Lower Tertiary alluvial fan deposits in the area of the Montagne Sainte Victoire (Provence, Southern France) preserve alluvial-tectonic relationships related to the evolution of the eastern Pyrenean-Provencal foreland basin. Controversial interpretations of kinematics, amount and nature of shortening (autochthone vs. allochthone), and timing of deformation within this foreland basin result from: (1) the tectonic overprint by Oligocene extension, Miocene opening of the Golf of Lyon to the south, and late Eocene to present-day Alpine reactivation to the east and north; and (2) the occurrence of complicated alluvial-tectonic relationships showing both north as well as south verging structures. In this abstract we describe alluvial-tectonic relationships in the Montagne Sainte Victoire and discuss their implication for the kinematic evolution of the Late Cretaceous/Early Tertiary Pyrenean-Provencal foreland basin.

Former descriptions of Upper Cretaceous/Lower Tertiary alluvial fan deposits distinguished two distinct phases of deposition which were separated by a deformation event (Ruiz Barragan, 1978; Tempier and Durand, 1981). Our observations, however, rather suggest that the alluvial fans formed simultaneous to convergence. This is nicely demonstrated by the occurrence of growth structures in the area north of Le Tholonet. In this area, onlap surfaces can be observed within fold limbs whereas the fold hinges are locally eroded and sealed by younger breccias which in turn are folded around the same fold axis. Basal, south-vergent thrust faults soling the growth folds are exposed in the area of Les Harmelins. These faults ramp into alluvial fan deposits, within which they die out. At the eastern end of the Costes Chaudes, growth structures are cut by a fault along which Mesozoic limestones forming the Montagne Sainte Victoire were thrusted towards the south. East of the Cengle syncline, growth-structures and alluvial fan deposits disappeare. Further to the south, the Mesozoic rocks abut on Upper Cretaceous/Lower Tertiary breccias forming E-W striking folds geometrically associated with the Montagne du Cengle syncline. Within this syncline, the occurrence of folded Eocene deposits shows that one part of N-S shortening has to be Eocene or younger and post-dates the deposition of alluvial fan deposits.

Alluvial-tectonic relationships show that south-vergent structures, which are apparently in conflict with the generally accepted north-verging Pyrenean-Provencal foreland basin, are closely associated with alluvial fan deposits and appear to coincide regionally with places where potential decollement horizons change abruptly their depth (Biberon,

1988). One possible explanation is that during general N-vergent thrusting of the Provence, pre-existing perturbations of the deep structure of potential decollement horizons let to ramp structures of limited lateral extension. Along these ramps, S-vergent structures developed simultaneously with the formation of topography and correlative alluvial fans. This interpretation may support an allochthonous origin of the Montagne Sainte Victoire.

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Ruiz Barragan R, *Thesis, Université Pierre et Marie Curie, Paris 6*, 129p, (1978).
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OS04 : SUpo09 : PO

Tectonic-Sedimentation Relationships within a Variscan Wedge-Top Depozone: Example of the Western Meseta (Massif Central, Morocco)

Mohamed Ben Abbou (benabbou@hotmail.com)[1],
Jean-Claude Soula (geostruc@cict.fr)[2],
Stéphane Brusset (brusset@cict.fr),
Roddaz Martin, **Beziat Didier** (dbeziat@cict.fr)[3],
Déramond Joachim[4], **N'Tamouchant Ahmed**[1] &
Driouch Youssef[1]
[1] Faculté des Sciences de Fes, Fes, Maroc
[2] Laboratoire Dynamique des Bassins, Toulouse, France
[3] UMR 5563 LMTG, Toulouse, France
[4] Dynamique des Bassins, Toulouse

In the Variscan Massif Central of Morocco, a reappraisal of tectono-sedimentary data leads us to characterize a foreland basin system (DeCelles and Giles, 1996). This area is constituted by a succession of seven depocenters of Late Visean to Early Westphalian age and linked to north-western thrust propagation. Tectonic features of the Western Meseta correspond to northwest-verging thrusts associated with southeast verging backthrust linked to passive roof duplexing. Tectonic-sedimentation relationships clearly evidence that this growth folds belong to a wedge-top depozone. Turbiditic and gravity flow deposits corresponds to catastrophic sedimentation that interferes in the storm-dominated facies. The specific stacking pattern of catastrophic sedimentation is usually retrograding and shows a rapid increase in accommodation rate. This increase is consistent with the progression of thrust tips toward the basin while creation of thrust-related folds generated slopes likely to be recorded by gravity flow deposits. This sedimentary organization is well-defined in the Azrou and Fourhal basins and new data show that it can be branched out into the whole western Meseta. The stratigraphic distribution of syntectonic strata allow to time-calibrate the thrust propagation within the wedge-top depozone. The successive geometry of the wedge-top depozone restored at different stages of the thrust-propagation. Additional magmatic data allow to demonstrate that the Western Meseta of Morocco belongs to a retro-foreland basin system.

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OS04 : SUpo10 : PO

Origin of the Upper Cretaceous-Tertiary Sedimentary Basins within the Tauride-Anatolide Platform in Turkey

Ömer Feyzi Gürer (feyzigurer@yahoo.com)[1] &
Ercan Aldanmaz
(ercan_aldanmaz@hotmail.com)[2]
[1] Kocaeli University, Engineering Fac., Dept. of Geology, Vinsan, Izmit/Kocaeli, Turkey
[2] Kocaeli University, Engineering Fac., Dept. of Geology, Vinsan, Izmit/Kocaeli, Turkey

A number of sedimentary basins formed within the Tauride-Anatolide platform of Anatolia during the Late Cretaceous-Tertiary period. Previous studies have proposed different tectonic and evolutionary models for each basin (e.g., active continental margin and/or back-arc or fore-arc environments). These studies mostly concentrate on the existence of an oceanic basin, known as the inner Tauride ocean, and they explain the formation of the basins in a relation with the closure of this ocean. Geological characteristics of the basins, however, suggest that all these basins are of the same origin and that they followed an evolutionary model similar to one another. Both marine and terrestrial sequences deposited in the basins during the Late Cretaceous-Early Miocene, while the post-Late Miocene period is represented by only terrestrial deposits. The sedimentary and volcanic rocks that formed over a thousand of meters of sequences filled the basins. The sedimentary successions in the basins rest mostly on ophiolite and melange associations suggesting that the basins formed on ophiolite obductions. After the Late Cretaceous, following the terminal closure of the Neo-Tethys ocean which were located between the active continental margin of the Pontide volcanic arc to the north and the passive continental margin of the Tauride-Anatolide platform to the south, the ophiolitic rocks of this ocean obducted onto the Anatolide-Tauride platform as nappes. The obduction of the ophiolites lasted until the Late Miocene. The sedimentary basins, located between the Aegean Sea to the west and the Turkish-Iranian high plateau to the east, formed as piggy-back basins on these nappes.

OS04 : SUpo11 : PO

Variscan Molasse and its Metamorphic Basement: Swiebodzice Basin, Polish Sudetes

Ryszard Kryza (rkryza@ing.uni.wroc.pl) &
Marek Kulczynski (mkul@ing.uni.wroc.pl)
Wroclaw University, Institute of Geological Sciences, Cybulskiego 30, 50-205 Wroclaw, Poland

The Swiebodzice Basin (SB) in the central Sudetes, SW Poland, interpreted as a small pull-apart basin, is filled with Upper Devonian and Lower Carboniferous Variscan syn-orogenic molasse. The molasse is in contact with the blueschist-to-greenschist facies metamorphic Kaczawa Complex (KC) to the north. Broadly similar epimetamorphic rocks appear, locally, also within the SB. The relationships between the metamorphic rocks and the unmetamorphosed molasse are important constraints for the tectonic evolution and timing of orogenic events in this part of the Variscan Belt. Particularly intriguing are the problems of (a) structural relationships between the KC and the SB, and (b) the sedimentary facies contrast between the Upper Devonian rocks within the KC (pelagic sediments) and in the SB (molasse).

The metamorphic rocks exposed in the SB comprise mainly diabases (metadolerites) and the so called 'Cieszow Cataclasites' (CC), the latter regularly surrounding the diabases, and separating them from the Devonian sediments. The outcrops of the metamorphic rocks within the molasse have been variously interpreted, e.g. as (a) exposed fragments of the basement, (b) the uppermost nappe of the KC (Cieszow Unit) thrust southward over the Devonian sediments (the CC being considered as products of intense deformation at the base of the nappe).

New observations made in two excavation sites (trenches 3 m deep and up to 24 m long) and in nearby exposures at the contact between the metamorphic rocks and molasse at Chwaliszow, NW of Swiebodzice, indicate that: (1) The 'Cieszow cataclasites' represent mylonites and cataclasites developed from a granite protolith, under ductile/semi-brittle and brittle conditions, during multi-stage deformation. Together with the associated diabases, they are rather different from the rocks of the KC, and more similar to lithologies known from areas south of the Main Intra-Sudetic Fault (Rudawy and Klodzko units). (2) The contact zone between the CC and the Devonian molasse is complex, but, based on new observations, the studied northern part of the Cieszow Unit may represent a southwardly overturned synform, with the Devonian sediments at its core, and the structurally underlying metamorphic basement rocks (diabases and cataclasites) on its limbs. In such a case, thus, the epimetamorphic rocks represent the basement of the SB, and not a crystalline nappe, the opposite of the previous, widely accepted model.

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OS04 : SUpo12 : PO

The Rôle of Syntectonic Decollement Level in Front of Thrust System

Thierry Nalpas (thierry.nalpas@univ-rennes1.fr)[1],
Jaume Verges (jverges@ija.csic.es)[2],
Gail Le Roux[1],
Denis Gapais (denis.gapais@univ-rennes1.fr),
Delphine Rouby
(delphine.rouby@univ-rennes1.fr) &
Laurie Barrier (laurie.barrier@univ-rennes1.fr)
[1] Géosciences Rennes, Université de Rennes 1, 35042 Rennes, France
[2] Institute of Earth Sciences Jaume Almera, CSIC, 08028 Barcelona, Espagne

The role of pretectonic décollement levels in the structural evolution of compressive basins is largely documented by fields examples (Davis and Engelder, 1985; Baby et al., 1989; Ballard, 1989; Verges et al., 1995), as well as in modeling approaches (Colletta et al., 1991; Tondji Biyo, 1995). For example, it is clear that the location of major faults within compressive basins is determined by the presence of décollement levels. We discuss here the role of syntectonic décollement levels deposited in front of an active thrust zone. The field example is the northeastern part of the Ebro Basin (Spain). There, the location of the main thrusts is not always perpendicular to the direction of compression. Lateral ramps occur, controlled by the location of a basal pretectonic décollement level. Other décollement levels were deposed during the Pyrenean compression in front of the thrusts. The structures generated during compression, above these syntectonic décollement levels, are generally parallel the main thrust and can be oblique to the main compression direction, where the main thrust is a ramp. Analogue modeling has been used to study the evolution of such compressive systems. The effects of syntectonic décollement levels have been examined for different geometries of pretectonic décollement levels. The results suggest that the direction of the structures created above a syntectonic décollement level depends on the direction of the main thrust. Where the main thrust is not perpendicular to the main compression direction, for example in a lateral ramp, a local direction of compression is created if a décollement level is present in front of the thrust, and structures can then develop perpendicularly to a local direction of compression. This feature can perhaps explain the occurence of the NNE-SSW folds observed locally along the Southeastern Pyrenean front.

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OS04 : SUpo13 : PO

Simulating the Stratigraphic Architecture of the Lower to Middle Miocene Central Vienna Basin (Austria)

Hanns Peter Schmid
(hanns.peter.schmid@univie.ac.at) &
Michael Wagreich
Inst. f. Geologie - Univ. Wien, UZA II, Althanstr.14, A-1090 Vienna, Austria

The change from the Lower Miocene piggy back stage to Middle Miocene pull-apart stage of the Vienna Basin is recorded in the shift from terrestrial-fluvial to shallow marine sedimentation. Middle Miocene depocenters evolved by duplexing between major NE trending sinistral faults. Syntectonic deposition within two transgressive sequences during the Middle Miocene resulted in a complex depositional pattern in small subbasins. Based on a wealth of data from seismic surveys and wells we try to decipher the stratigraphic architecture along a 2D seismic section by forward modelling. The presented section crosses the whole central Vienna Basin in a WNW-ESE direction and is almost perpendicular to the main basin axis.

Using the process-orientated software package 'PHIL' (PetroDynamics Inc.) allows to evaluate quantitively controlling factors such as sediment supply, tectonic subsidence and eustasy. Digitization of seismic lines creates time lines used as a framework for the simulation runs. The following backstripping process gives approximate values for sediment supply and tectonic subsidence along the cross section. The start off default model is completed with informations from well-logging data sets (spontaneous potential and resistivity logs). Sedimentation controlling variables are continously modified until the final model fits the observations made in the seismic section.

OS04 : SUpo14 : PO
Exhumation and Sedimentation – The Example of the Central Alps: II. Sandstone Composition

Hilmar von Eynatten (eynatten@geo.uni-jena.de)
Institut fuer Geowissenschaften, Burgweg 11, D-07749 Jena, Germany

Both, distribution and composition of sediments in foreland basins mirror tectonic processes in the adjacent orogen. Sediment distribution is largely controlled by morphology, subsidence of the foreland plate, sediment flux into the basin, and relative sea level variation. Sediment composition is largely controlled by source rock lithologies and weathering (climate). This study relates compositional changes of sandstones of the Swiss Molasse Basin to the structural evolution of the Cental Alps using a multimethod approach to sandstone composition.

Forty sandstones from six depositional systems were sampled covering the Swiss Molasse Basin from Lake Geneva in the west to Lake Constance in the east. Samples are dated very precisely by magnetostratigraphy and range from Lower Oligocene (31 Myr) to Middle Miocene (13 Myr). Sandstone composition is analysed mineralogically and chemically by four different methods leading to the following data sets: light minerals (LM), heavy minerals (HM), major elements (ME), and trace elements (TE).

Both LM and ME data suggest mixing of carbonate and silicate sources. Carbonate contribution (limestone and dolomite) is generally higher in the eastern depositional systems and in sediments older than 25 Myr. In the western depositional systems alkali/silica ratios are generally higher with highest values in the time slice 25 - 20 Myr. The latter correlate with high feldspar contents and are interpreted to reflect erosion of feldspar rich crystalline rocks. HM data suggest a major change in source rock composition at 25 Myr in the west and at 21 Myr in the east when epidote become the major heavy mineral phase. Because epidote is present in greenstone as well as granitoid conglomerate pebbles, it is thougt to derive from both acidic and basic source rocks. Chrome spinel as indicator of ultrabasic sources is mostly restricted to Oligocene strata, but in the eastern section it is present throughout the stratigraphic column. TE data are most useful to prove primary ultrabasic sources and to detect sediment recycling (e.g., erosion of Penninic flysch nappes).

The results stress the importance of multi-method approaches to sandstone provenance. The study underlines that all major changes in the structural evolution of an evolving orogen are documented in the composition of contemporaneously deposited sandstones. Judging from the sediment to the source, it is possible to identify all of the major source rocks, to constrain modification by weathering, and to resolve source rock variations in space and time. But it is not possible to unambiguously identify exhumation processes like those of the Oligo/Miocene Lepontine dome from sandstone composition alone. In such cases varietal studies (chemistry and geochronology) of single detrital grains are most promising

OS04 : SUpo15 : PO
Provenance Analysis of Silurian to Carboniferous Siliciclastic Formations, Pisuerga-Carrion Nappe, Cantabrian Mountains, Spain

Heinrich Bahlburg (bahlbur@uni-muenster.de)[1], **Maja Bäumer**[1], **Jürgen Kappel**[1] & **Barbara Teichert**[2]
[1] Geol.-Paläont. Inst., Corrensstrasse 24, D-49149 Münster, Germany
[2] Geomar, Wischhofstrasse 1-3, D-24248 Kiel, Germany

We present first results of a provenance study of Paleozoic formations of the Pisuerga-Carri-n nappe in the southeastern Cantabrian mountains. We trace the mineralogical and geochemical evolution recorded in sandstones ranging in age from the Upper Silurian to the Upper Carboniferous. Sampled units include the Carazo Formation (Ludlow-Gedinne), the Moradillo and Murcia formations (Frasnium-Famenne), the Vegamian black shales (Famenne-Tournais) and the Carmen Formation and Potes Group (Westfalian A). With regard to the onset of orogenic shortening leading to the formation of a foreland basin and eventually the Hercynian mountain belt in this region, the Upper Silurian to Lower Carboniferous units are in the literature considered to be pre-orogenic, the Upper Carboniferous ones are classed as synorogenic.

The arenites of the Carazo, Moradillo and Murcia formations are quartz-sandstones, whereas the Carmen Formation and Potes Group are made up of lithic arenites and greywackes. All rocks are poor in feldspar, rock fragments consist almost exclusively of sedimentary and metasedimentary rocks. The heavy mineral populations of all formations are dominated by the association of the stable minerals zircon, rutile and turmaline. Geochemically, the rocks can be classed as quartz-intermediate and quartz-rich. CIA values range from 40 to 90 and indicate a strong weathering influence especially for the Murcia Formation and some parts of the Potes Group. Th/Sc ratios are close to or higher than 1 and point to an upper crustal composition of the detritus. Zr/Sc ratios >50 indicate significant reworking and concentration of zircon mineral grains in the quartz-rich Carazo, Moradillo and Murcia formations. The synorogenic Carmen Formation and Potes Group samples do not show this effect. REE patterns are parallel to PAAS but mostly show depleted REE abundances.

The studied formations have an overall upper crustal composition. The framework mineral association, the heavy mineral spectra and the geochemical data indicate that the detritus was derived through significant and probably repeated recycling of older sedimentary source rocks. There is no indication of contemporaneous or older volcanism.

OS04 : SUpo16 : PO
U-Pb Detrital Zircons Ages and Nd-Isotope Systematics as Provenance Indicators in Lower Palaeozoic Sediments from the Avalonia/Baltica Borderland

Axel Gerdes (ager@bgs.ac.uk)[1], **Marco Vecoli** (vecoli@geologie.uni-halle.de)[2], **Uwe Giese** (giese@geologie.uni-halle.de)[2], **Hilke Timmermann** (hti@nigl.nerc.ac.uk)[1], **Matthew Horstwood** (msah@nigl.nerc.ac.uk)[1] & **Randall R Parrish** (rrp@nigl.nerc.ac.uk)[1]
[1] NERC Isotope Geosciences Laboratory, Keyworth, NG12 5GG, U.K.
[2] Institut fur Geologische Wissenschaften, MLU-Halle Wittenberg, 06108 Halle, Germany

Provenance studies of clastic sediments deposited in orogenic belts can provide important information for plate tectonics and palaeogeographic reconstructions. We present U-Pb age distribution of detrital zircons and Nd isotope systematic of Early Palaeozoic clastic rocks from the subsurface of NE Germany, Denmark and NW Poland. Previous investigations indicate a Caledonian tectonothermal event at the Ordovician-Silurian boundary and the transition from an Avalonia- to Baltica-related sediment provenance in Late Ordovician times in the Baltic Sea area of NE Germany (Dallmeyer et al., 1999, Vecoli et al., 2000). Biostratigraphic and palaeobiogeographical information indicate closure of the Tornquist Ocean due to the Avalonia-Baltica collision before Ashgill (Samuelsson et al., 2000). Late Cambrian to Middle Ordovician shales and sandstones from deep wells in northern Germany (Rügen-5 and Flensburg-1) show typical Avalonian Nd isotope signatures with $\varepsilon Nd_{(T)}$ between -8.6 to -6.5. In contrast, Cambrian sandstones and shales from the southern Baltic Sea (borehole G14), and NW Poland (boreholes Leba-8, Bialogora-1 and Zarnowiek-7) yield $\varepsilon Nd_{(T)}$ values of -9.2 to -15.3, indicating clastic provenance from old cratonic sources (Baltica). However, the $\varepsilon Nd_{(T)}$ signatures (-7 to -6.6) of Middle Ordovician shales from borehole G-14 (southern Baltic Shield) are comparable to contemporaneous sediments from the Avalonian margin (Gerdes et al., 2001), suggesting a similar input of juvenile, volcanoclastic detritus at that time. This may signify that Avalonia was relatively close to Baltica already in Middle Ordovician times, and agrees with palaeomagnetic data suggesting similar latitudes for Avalonia and Baltica at around 470 Ma (Trench & Torsvik, 1992). Moreover, this seems to indicate that mixture of sediments of Baltica and Avalonia provenances, deposited in a foreland basin on the shelf of Baltica, may have occurred since the Middle Ordovician (Vecoli et al., 2000; Samuelsson et al. 2000). During the Silurian, $\varepsilon Nd_{(T)}$ values of sediments from NE Germany and NW Poland drop from -7.6 to -10, indicating the increasing input of unradiogenic detritus due to the collision of Baltica with Laurentia forming the Scandian Orogen. In contrast, Ordovician and Silurian sandstones and shales from the Danish basin show uniform $\varepsilon Nd_{(T)}$ values of -9.4 to -10. Selected single zircon grains from Cambrian through Silurian sandstones were analysed for U-Pb dating by laser ablation plasma-ionisation multi-collector mass spectrometry (La-PIMMS). Cambrian sandstones from the Leba-8 and G-14 wells are dominated by zircons with ages of around 1530 and 1730 Ma indicating a Gothian provenance. Sveconorwegian and older Mesoproterozoic ages were found in zircons from Ordovician sandstones from the Danish basin and the Silurian of Rügen.

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OS04 : SUpo17 : PO
Donbas Siltstone Sandstone as Indicators of Specific Tectonic Regime

Valentina Vishnevskaya (valentina@ilran.ru)[1], **Pavel Fokin** (fokin@geol.msu.ru)[2], **Kuljash Sedaeva**[2], **Nikolay Bojko**[3], **Aleksandr Khardikov**[3], **Anatoly Vertjukh**[4] & **Tom McCann** (tmc@gfz-potsdam.de)[5]
[1] Institute of the Lithosphere, of Marginal Seas, Russian, Academy of Sciences, Russia
[2] Moscow State University, Russia
[3] Rostov-on-Don, University, Russia
[4] Chernigov branch of, Geological Institute, Ukraine
[5] GeoForschungszentrum, Potsdam, Germany

Typical Middle Carboniferous sandstones of the Donets Basin are mid-sorted with the gradation turbidite structure. Sandstones are composed of quartz and feldspar mainly, with carbonate, highly sericitized clayey or regeneration quartz cement, which makes up to 30% of the rock. The clasts are represented by quartz (35-70%), feldspar (15-30%), partially rounded fragments of quartzite, granite (up to 10-15%) and biotite, probably of volcanic derivation partially (about 10-15%). Composition of heavy minerals series indicates the supplement of clastics from intrusive and metamorphic complexes. The extra-high content of biotite and ferriferous chlorite points the active tectonic regime with probable synchronous volcanism and erosion of endogenic and sedimentary rocks both. The conformed contacts of grains, stilolites, type of cement shows catagenetic stage of processing, comparable to subsidence up to 3-4 km. Variable grade of the postsedimentary processing probably reflects the intensity of tectonic reworking of the rocks also. Light-coloured arkose pudding fanglomerate with numeral clasts of radiolarites are characteristic to Middle Carboniferous sediments. That fragments of radiolarites are of different types including organic-rich, their shape varies from angular to well round. Numerous grains of thin-laminated Lower Carboniferous radiolarites often have angular shape and it is the evidence of proximity of their supplying province. The well-rounded grains of siliceous rocks, and radiolarites also, could be transported from the distant territories. Some grains have undergone the initial stage of dolomitization, with dolomite crystals being conformly cut to the rim of grains. It may indicate the tectonic inversion event before the surfacial destroying of radiolarite rocks. Some radiolarite clasts contain quartz veins, exhibiting that the parental siliceous rocks were subjected to some tectonic reworking with opening of gashes and their filling with quartz. The typical kind of sandstones belongs to a group of the quartz-feldspar-micaceous rock graywacke. The feldspar-quartz micaceous sandstones often contain biotite stripes, probably derived from pyroclastics. Selective composition suggests a regime of fast subsidence of the basin and rapid buriment of the sediments in the basin.

OS04 : SUpo18 : PO
Lithological and Mineralogical Aspects of Placer Accumulations Forming on the Northwestern Black Sea Shelf

Natalya Fedoronchuk (marine@paco.net)
149/3, kv. 68, Dobrovolsky av., Odessa, 65111, Ukraime

Lithological features of sea bottom sediments and formation of shelf placer accumulations depend on hydrodynamic conditions as well as waves and currents. According to hydrodynamic factors maximal thickness of marine Holocene sediments on the northwestern Black Sea shelf are in depression of sea bottom relief which are ‘raps of sediments’, and minimal thickness of sediments are on elevated places. Sands, calcareous detritus, and calcareous, silt and silt-clay mud are most common sediments on the shelf. Main placer accumulation minerals on the shelf are titanium-bearing minerals, zircon and, sometimes, garnet. Most common titanium-bearing minerals here are ilmenite, rutil and leucoxene, but anatase and brookite are appeared rather seldom. Regular concentration of ilmenite is ca. 0.2 kg/m^3, contents of rutile and leucoxene are varied from zero to 0.2 kg/m^3, and high content of zircon is specific for eastern part of the shelf, but increased concentrations of the minerals are measured eastward Zhabriyany bay, southward the Dnester estuary, near Budak estuary, in Odessa bay, buried Dnieper channel (Dnieper depression), and near Kinburn and Tendra spits. Garnet content in sea bottom sediments of the shelf does not change visible, however its relatively high concentration are known at the some places like ilmenite, rutile and leucoxene. Lithological and mineralogical features of Holocene sediments (chernomorsky and novoeuksine ages) located in Dnieper depression and near Tendra spit areas have been detail studied. Typical terrigeneous mineralogical assemblages have been separated. Statistical treatment of the results and comparison of grade analysis data with mineralogy of sediments are the base for following conclusions. Placer accumulation are formed on both nearest offshore and more deeper part of the northwestern Black Sea shelf where small and fine minerals are dominated. There are two types of placer accumulation here. First one has titanium and zircon mineralogical speciality. Concentration of minerals depends on hydrodynamic conditions and transportation and deposition of the minerals are realized according to well-known peculiarities for placer accumulation formation on littoral areas. However, it has been discovered that high concentration of the minerals is not only in narrow areas near to the coast, but it keeps being high up to 20-30 m depth due to minerals of fine sizes. Second type is accumulation of fine gold in sea bottom sediments. It is formed in relatively deep areas where specific hydrodynamic conditions facilitate concentration of fine size gold which can not be stopped near the coast and is moved as suspended load rather far from the coast. Fine gold are concentrated on any zones where hydrodynamic conditions are dramatically changed and appeared as hydrodynamically passive or turbulent ones, and zones of energy lost due to any bariers.

OS04 : SUpo19 : PO
The Deimlinger Mühle Outcrop: A Key Locality for the Oberrotliegend and Buntsandstein in the Trier-Bitburg Basin (Southwest Eifel, Germany)

Eric A Lichtenscheidt
(eric.lichtenscheidt@t-online.de)
Immenburgstr. 20, 53121 Bonn, Germany

The outcrop at the Deimlinger Mühle is situated in the Kyll valley between the villages of Daufenbach and Kordel (r ^{25} 46 560 h ^{55} 25 520). SE-dipping lower Devonian rocks occur up to 5 m above road level. They are surrounded and unconformably overlain by red clastics of the Oberrotliegend as well as of the Mittlerer and Oberer Buntsandstein of the Trier-Bitburg Basin.

At the base of the Permotriassic sequence, a muddy horizon occurs which is interpreted in terms of weathered Unterdevon rocks (former land surface ?). Above it, a clast-supported, scarcely cemented conglomerate is found containing well-rounded clasts. Among them, Unterdevon red sandstones are found bearing fossils of late Emsian in age. Clast imbrication indicates a sediment transport toward the Southwest. Another characteristic of the conglomerate is its extraordinarily intense purple-red colour. These observations suggest that this unit belongs to the Oberrotliegend.

Following a gap, a sequence of layers appears at 19.5 m above road level consisting of debris-flows, fluvial sandstones with some pebbles, as well as of finegrained clastics. ‘Fining-upward’ cycles can be seen. Age classification of this sequence remains uncertain and has to be discussed because debris flows are typical sedimentological features of Oberrotliegend and Mittlerer Buntsandstein 2 in this region.

Certainly the beds from 34.5 m upwards can be assigned to the Mittlerer Buntsandstein 2 (‘sm_2’ of the local stratigraphy of Negendank 1983).

Geological mapping brought further knowledge as the outcrop is located in a high position in the centre of a network of normal faults with a maximum downthrow of about 260 m. Throws of such a size are untypical in the Trier-Bitburg-Luxemburg Basin. The results of numerous wells drilled for water can be added to this model as well, and it can be assumed that the structure represents a fault active during Oberrotliegend and Buntsandstein as well. This fault was reactivated in post-Triassic times. The movements during the Mittlerer and Oberer Buntsandstein can be reconstructed useing variations in sediment thickness. The areas north and south of the fault have subsided about 100 m more than the central area with the Devonian outcrop.

From this I conclude that the outcrop at Deimlinger Mühle marks the northwestern margin of a small Oberrotliegend basin (‘Gladbach Basin’ Schrader 1990). This basin terminates near Arenrath in the NE and at the Naurath horst in the E (Ashraf & Stets. 1978). Toward the SE the Oberrotliegend series of the Wittlich Basin follow. Toward the south, these series can be traced to the northwestern edge of the Hunsrück. Toward the SW, the basin disappears under a Mesozoic cover. The basin runs roughly parallel to the Wittlich Basin, but it is separated at least by the Naurath horst in the NE.

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OS04 : SUpo20 : PO
Chronology and Geodynamic Evolution of the Late Miocene Basins of the Eastern Betics (Spain)

Esther Van Assen (vanassen@geo.uu.nl)[1], **Wout Krijgsman**[1], **Miguel Garcés**[2] & **Fransisco Sierro**[3]
[1] University Utrecht, Budapestlaan 17, 3584 CD Utrecht, The Netherlands
[2] Institute of Earth Sciences Jaume Almera, CSIC, Barcelona, Spain
[3] University of Salamanca, 37008, Salamanca, Spain

The late Miocene depositional history of the Lorca and Fortuna basins, situated in the eastern Internal Betics (SE Spain), is marked by a regressive sequence from open marine marls, via diatomites and evaporites, to continental sediments. Based on facies similarities, these evaporites have often been correlated to the well-known Mediterranean evaporites of the Messinian salinity crisis. Recently, however, new integrated stratigraphic data showed that evaporite deposition in Lorca and Fortuna was related to a local tectonic phase which initiated the so-called Tortonian salinity crisis of the eastern Betics (Krijgsman et al., 2000). In contrast, the sedimentary infill of the neighbouring Murcia-Cartagena basin consists of a continuous marine sequence from late Tortonian to late Messinian age.

Here, we will present the integrated stratigraphic results from the Murcia-Cartagena basin, which allow a straightforward comparison with the new depositional history of the Lorca/Fortuna area. Our results require a completely new interpretation of the tectonic/geodynamic and sedimentary evolution of the late Miocene basins of the eastern Betics.

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OS04 : SUpo21 : PO
Sequence Stratigraphy and Tectonic Control of the Baltic Silurian Foreland Basin

Jurga Lazauskiene (jurga.lazauskiene@lgt.lt)[1], **Saulius Sliaupa** (sliaupa@geologint.lt)[2], **Petras Musteikis** (petras.musteikis@gf.vu.lt)[3] & **Antanas Brazauskas** (petras.musteikis@gf.vu.lt)[3]
[1] Lithuanian Geological Survey, Konarskio 35, Vilnius, LT-2600, Lithuania
[2] Institute of Geology, Sevcenkos 13, Vilnius, LT-2600, Lithuania
[3] Vilnius Universty, Ciurlionio 21/27, Vilnius, LT-2600, Lithuania

The Baltic Basin overlaps the SW margin of the East European Craton (EEC). During the Silurian its subsidence was governed by the flexural bending of the EEC, induced by docking of Eastern Avalonia to Baltica. Tectonic, geochemical, sequence stratigraphy analysis, combined with geodynamic and sedimentary numerical modelling, were applied to reveal the tectonic-sedimentary evolution of the Baltic Silurian foreland basin (BSB) focusing on the interplay of geodynamic processes to the development of sedimentary architecture.

3D geodynamic modelling suggests that the BSB evolved under the influence of two mechanisms, refered to as orogenic and dynamic loading. The moderate wavelength subsidence of the BSB may be related to Caledonian orogenic loading. The additional mechanism, possibly related to the subduction-induced sub-lithospheric dynamic loading, contributed to the long-wavelenght (650 km) subsidence of the basin. Rheological properties of the lithosphere strongly influenced the basin geometry. The weakest lithosphere (EET=20 km) is characteristic for the central part of the basin, increasing towards the margins (EET=40-50 km). This would imply that the basin lithosphere is less resistant to the tectonic forces in comparison with adjacent structures.

Adopting a sequence stratigraphic aproach, ten depositional sequences, corresponding to the Early Llandovery, Middle-Late Llandovery, Early Wenlock, Late Wenlock, Early Ludlow, Middle Ludlow, early Late Ludlow, late Late Ludlow, Early Pridoli, and, Late Pridoli were recognized in the BSB. They are composed of lower order cycles, distinguished on a basis of lithofacies and log correlation. The architecture of sequences in the BSB is strongly dependent on tectonic processes in the evolving foreland system that was also shown by the quantitative sedimentary modelling. 2D basin infill modelling allowed the evaluation of different factors (volumes and penetration distance of two-side terrigenous inflow, paleobathymetry, subsidence etc.) influencing the sedimentation in the BSB. Geochemical studies indicated the onset of Caledonian sourcing in the Asghill already. The Llandovery sequences represent the starvation stage of basin evolution and shows an uncompensated sedimentation regime, where flexural downwarping outpaced sedimentation rates. Depositional sequence architecture indicates gradually increasing subsidence and westward deepening of the basin. The low influx of terrigeneity may be explained by a distant position and the low topography of the Caledonian orogen. The Wenlock-Middle Ludlow succession represents a transitional stage with a gradual increase in terrigenous input and increasing subsidence rates. Sedimentary architecture during the Late Ludlow-Pridoli represents the infilling stage of the basin development. Here the dramatically increased inflow of Caledonian-sourced sediments outpaced still accelerating subsidence, reflecting the advancement of the Caledonian thrust-belt. The provenance of the Fennoscandian-Sarmatian platform in the east accounts only for sedimentation in the eastern half of the basin.

OS04 : SUpo22 : PO
The Comparative Analysis of Linear and Exponential Change Density with Depth in Sedimentary Basins (An Example of the Black Sea Basin)

Olga Legostaeva (olgal@igph.kiev.ua)[1], **Irina Makarenko** (irinam@igph.kiev.ua), **Vitaly Starostenko** (vstar@igph.kiev.ua) & **Sergey Stovba** (stovba@geofiz.kiev.ua)[2]
[1] Institute of Geophysics NAS of the Ukraine, Palladin, av.32, Kiev, Ukraine, Ukraine
[2] Technology Center Ukrgeofisika, 10, S. Perovska, Kiev, Ukraine, Ukraine

The aim of this investigations is study of the density features of the sediments of the upper part of the Black Sea Basin using the available wells data and presentation of the density as function of depth in analytical form. The study area covers the north-west shelf and the deep-water part of the Black Sea Basin. We have used data from 19 wells. The maximum depth of the wells used in the study was 4 km. The analysis of data obtained shows that in the 0.3-1.5 km interval the density in the sediments changes both by linear and by exponential law, depending on geological situation. The density changes according to linear law in wells where sediments occur evenly without wedging of any stratigraphic horizons. As a rule, the first 2-3 km in these wells are occupied by young (Pliocene-Quaternary-Maikop) rocks. In the wells where young sediments overlie more ancient (e.g. Cretaceous) the density changes according to the exponential law. This sediments are highly dislocated in the NW shelf of the Black Sea basin. For the deep-water part of the basin density data are only available for two wells whose depth is not more than 1 km. But the density changes here according to the exponential law. Conclusions: the researches made show that for the Black Sea basin sediment (to depth of the order of 2.5-3 km) densities change according to the exponential law generally written as: $\rho(H)=2.7-1.3\exp(-0.77H)$ is characteristic. It should take into consideration in gravity modelling. The gravity modelling of interesting parts of Black Sea was made and new data about it geological construction was received. The tectonic interpretation of density models is made.

OS04 : SUpo23 : PO
Origin of Rapid Changes of Sea Depth in Sedimentary Basins: Eustasy or Tectonics

Eugene V. Artyushkov (pchekh@ilran.ru)[1] &
Peter A. Chekhovich (pchekh@ilran.ru)[2]
[1] Institute of Physics of the Earth RAS, B. Gruzinskaya 10, Moscow, Russia
[2] Institute of the Lithosphere of Marginal Seas RAS, Staromonetnyi per. 22, Moscow, Russia

Stratigraphic records and seismic profiling data exhibit numerous and rapid changes of sea depth in sedimentary basins. They are commonly explained by eustatic fluctuations of sea level; however, the influence of tectonics has been established for some regions. Third-order cycles in sea-depth changes with periods 1-3 Myr and amplitudes 20-100 m are of a special interest for petroleum geology. Such cycles have been earlier suggested for the Silurian. In the East Siberian sedimentary basin, ~ $2x10^6$ km^2 in size, a number of continuous stratigraphic sequences are available for this epoch. In many of them, slow deposition proceeded for 10-20 Myr at very shallow depths which did not exceed 5-10 m. The completeness of stratigraphic records in East Siberia with the absence of significant erosion allows us to estimate maximum possible amplitudes of the third-order cycles, which could have actually occurred in the Silurian. The analysis takes into account a finite rate of crustal subsidence and different forms of eustatic fluctuations. It appears that their amplitudes did not generally exceed ~20 m. For some subdivisions of the Silurian and certain periods of fluctuations, their amplitudes could not be larger than 5-7 m. During the same period of time, rapid changes of sea depth up to ~ 100 m occurred in North America, Southeastern Australia and South China. In the earliest Silurian, during 1-2 Myr, sea deepening by 100 m took place also in the north of East Siberia, while its southern part remained stable. At a relatively stable sea level, such sea-depth changes must be attributed to rapid vertical crustal movements. This is a new type of tectonic movements in cratonic areas, which are commonly supposed to be relatively quite. Basing on the data on East Baltic, it has been earlier shown that, in the Cambrian and earliest Ordovician, sea-level changes of a third-order type did not exceed 10-20 m. At that time, rapid changes in sea depth by ~ 50-100 m, indicating rapid crustal movements, however, occurred in Southern Sweden, Lithuania, and other regions. Crustal movements in cratonic areas took place in a rather uniform way throughout the Phanerozoic. Hence it is probable that no significant sea-level changes also occurred at many other epochs, while rapid changes in sea depth, established for such epochs earlier, actually resulted from vertical crustal movements. Physical mechanisms are discussed which can be responsible for such intense tectonic movements with short duration.

OS04 : SUpo24 : PO
The Gert Ridge: Architecture of an Inversion Zone in the Northern Danish Central Graben, North Sea

Kjeld Ghysels (kjhg@geo.aau.dk)[1],
Jens Peter Vind Hansen[2], **Ole Rønø Clausen**,
John A. Korstgård & **Poul-Henrik Larsen**[2]
[1] Geologisk Institut, Aarhus Universitet, 8000 Århus C, Denmark
[2] Department of Earth Sciences, C. F. Møllers Allé, Bygning 110, Universitetsparken, DK-8000 Århus C, Denmark
[3] Maersk Oil & Gas, Esplanaden 50, 1263 København K, Denmark

The Danish Central Graben is a pre-dominantly Mesozoic graben complex composed of a number of eastward dipping halfgrabens. During the late Cretaceous and Cenozoic selected fault trends (e.g. the Arne-Elin trend and the Lindesnes-Inge High complex) were inverted. The Gert Ridge is a structural high separating the Feda and Gertrud Grabens and is characterized by a NV-SE trending Late Jurassic complex fault system intersecting older N-S trending basement faults. The Freja Field is located at the center of the Gert Ridge in the northern part of the Danish Central Graben, which is a major target area for hydrocarbon exploration in the Danish sector.

Our study, mainly based on 3-D seismic data, shows that the pre Cretaceous succession is intensely faulted, with faults striking mainly NW-SE. However, the deeper horizons are also transected by faults striking N-S, which seems to be the oldest structural trend in the area. The adjacent Lindesnes Ridge and the Arne Elin Trend have an overall NNW-SSE strike. The Lower Cretaceous succession is also transected by faults, but the intensity of faulting diminishes during the Cretaceous, and the Upper Cretaceous succession is only slightly faulted. However, the thickness map of the Upper Cretaceous succession indicates that the underlying faults still was controlling the subsidence.

Inversion of the major faults of the Gert Ridge was initiated during the Volgian. The early inversion uplifted the hangingwall of the major fault (the Gert Fault) thereby generating a characteristic structural wedge of pre-Jurassic sediments. The inversion continued as discrete pulses during the post Jurassic, and the different phases are here interpreted to reflect the regional stress pattern, mainly originating from the Alpine orogeny. However, movements of Zechstein salt in the adjacent Lindesnes Ridge periodically controlled the evolution of the area. Differential subsidence across the Gert Ridge persisted during the Cenozoic, probably until the mid-late Miocene. A tectonic model combining transtensional and transpressional movements across the major fault zones and salt movements accounts for the structures observed.

OS04 : SUpo25 : PO
Fold Growth Mechanism and Geometries of Associated Syntectonic Sediments. An Example from Altomira Range (Iberian Chain, Central Spain)

Inmaculada Gil-Pe-A (i.gil@itge.mma.es)
ITGE, C/ Rios Rosas 23, 28003 Madrid, Spain

The deformation geometry linked with depositional geometries and the sedimentological analysis allow to infer a mixed folding mechanism: hinge migration and limb rotation for the detachment folds in the southern end of the Altomira Range (Mota del Cuervo area).

These folds formed over the Upper Triassic (Keuper facies) detachment level and involve a thin Jurassic and Cretaceous cover (less than 200 m thick) and the pre- and syntectonic Tertiary units (Paleogene- Middle Miocene). They are asymmetric box folds with complex hinge area.

The pre- and syntectonic sedimentary record comprises three major stratigraphic units separated by sedimentary discontinuities, linked with changes in the detachment fold cinematic evolution. The lower, Paleogene in age, is composed mainly by fluvial sandstones and conglomerates that lie paraconformably the mesozoic series. Its deposition predates, at less partially, fold growth. The intermediate unit, Paleogene-Neogene in age, is composed mainly by alluvial conglomerate with various source areas that eroded partially the underlying unit. Sedimentation is controlled by anticline growth. The rate of anticline uplift was higher than the sedimentation rate during the deposition of this unit, and the beds show offlap geometries. The upper unit, Lower- Middle Miocene in age, is composed by calcareous sedimentary breccia linked to the anticline crest, that fastly graded to red clays. The rate of anticline uplift was lower than the sedimentation rate, and this unit overlap the growth structures.

The lower and intermediate units show a clear parallelism with the pregrowth beds and their thickness remain roughly constant throughout the limb and syncline areas. These features are normally associated with growth strata deformed by hinge migration. In contrast, the upper unit shows bed thickness decressing in dip up-section and progressive thinning towards the fold crest, as it occurs in mechanism of limb rotation.

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OS04 : SUpo26 : PO
Disharmonic Folding of the Stylian Suite Versus its Lithology, the SW Donbas, Ukraine

Alexander Kitchka (kitchka@casre.kiev.ua)[1],
Vladimir Topolyuk (vlad@geofiz.kiev.ua)[2] &
INTAS Team
[1] CASRE, 55-b Gonchar Street, Kiev, 01601, UKraine
[2] TechCentre of Ukgeofisika, Perovska Street, Kiev, Ukraine

For decades quite exotic cherty marls of the late Early Carboniferous Stylian suite were an ‘apple of discord’ for stratigraphers, sedimentologists and structural geologists. This particular series of flyshoid beds, for the first time described by N.Lebedev at the end of XIX century, drastically differs from other ones of the Lower Carboniferous Massive Limestones in the SW Donbas by its peculiar lithology, appearance and very spectacular fold structures.

The suite is subdivided onto two units, and only the lower one so-called ‘Lower Visean E1’, up to 50 m thick, is subjected by fine folding. In the adjacent Dnieper Basin the Stylian suite is roughly corresponded to the Rudovka beds differing from other rocks of the section by high concentration of uranium and REE and substantial enrichment in organic matter content of sapropelic type.

Reportedly to previous studies some unusual rocks, called meta-bentonites, have been found in the section. V.Poletaev and S.Matchoulina (1995) have found and described those white, yellowish-creme clayey rocks which are in fact a deeply altered volcanic ash material, a product of submarine weathering (halmyrolysis). In general, the suite within the area studied is composed by 6 lithological types including dominating in the succession silicified and bleached slaty marls intercalated with aphanic ribbon cherts and meta-bentonites, and sporadically occurred immature sandstones, bituminous shales and, finally, newly found bedded phosphorites near the suite base (V. Yudin, personal communication).

The folds under consideration are typical mesoscopic ones. They are typical disharmonic (rarely polyharmonic) ones dying rapidly along axial surface; adjacent folds differ in terms of wavelength (from few decimeters to 50 m) amplitudes and symmetry, typically due to variation in physical properties and layer thickness. They do no affect the overlying and underlying strata and strike mostly to the NW that differs from true tectonic ones of higher order. Folds are of multivarious form: box folds, fan-like, isoclinal, symmetric and asymmetric, upright, inclined, recumbent and other ones. Ribbon cherts involved into folded structure are continuos that could speak in favor of soft-sediment or early diagenetic phase contemporaneous with folding. The observed kinkbands had been evidently formed due to more resistant lithology characterizing by alternating sandstones and ribbon cherts. In places where true tectonic faults cross the Stylian suite its rocks are totally crushed, brecciated and altered and those faults do not reveal any clear links to the folds under consideration. All those features led us to conclusion that the lower part of the Stylian suite was subjected by submarine/sub-aerial slumping.

Thus, it is proposed that folding of the Stylian suite was caused by local differential uplifting/subsidence and bed tilting triggering bed-parallel slip and efficient deformation of the sedimentary succession containing soft, incompetent layers.

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Monday AM Session

OS04 : MOam01 : G8
Facies Architecture and Evolution of the Late Permian Upper Rotliegend at the Northern Margin of the NE German Basin

Holger Rieke (rieke@gfz-potsdam.de),
Tommy McCann (tmc@gfz-potsdam.de) &
J. F. W. Negendank (neg@gfz-potsdam.de)
GeoForschungsZentrum Potsdam, Telegrafenberg, D-14473 Potsdam, Germany

The intracontinental NE German Basin (NEGB) is located between the stable Precambrian Baltic Shield to the North and the Caledonian/Variscan-influenced areas to the south. It forms part of the Southern Permian Basin, a series of interconnected basins extending more than 1500 km from England to Poland. The predominantly continental Upper Rotliegend strata were deposited under arid to semiarid climate conditions. A detailed stratigraphical subdivision of these successions is hampered by the lack of marker fossils and dateable marker horizons with the exception of the magnetostratigraphical Illawarra-reversal. New stratigraphical models for the Upper Rotliegend have been suggested for the British, Dutch and West German sectors of the Southern Rotliegend basin correlating facies distribution and climatically-related cyclicities. The existing lithostratigraphical subdivision for Eastern Germany, however, is based solely on tectonically-generated cyclothems with internal climate-driven cyclicity. Extensive examinations of more than 3.4 km of Rotliegend core material from thirteen wells across the northern margin of the NE German Basin led to the development of an independent facies model for the region. Six main subenvironments, namely alluvial fan, proximal, medial distal fluvial, playa and lacustrine have been recognised. The reevaluation of about 400 km of seismic profiles revealed a morphology dominated by several NE-trending channels. They can be correlated with similar observations made in more southerly parts of the NEGB and in western Germany. They are interpreted as extensional graben structures generated in an overall dextral strike-slip regime. These channels functioned as sediment feeder channels played an important role in the facies distribution within the Upper Rotliegend succession. The basinwide sedimentological evolution of the lowermost Parchim sediments was initiated by the post-Illawarra thermal-induced subsidence. Facies distribution, showing an initial expansion of braided stream floodplains followed by playa facies, was controlled by the former tectonically-created morphology. The Mirow formation is characterised by the basinward progradation of terminal fans. The uppermost Dethlingen and Hannover formations are largely influenced by evaporitic playa mud flat environments with associated perennial playa lake and salt flats. The resultant facies distributions are the result of a complex interplay of climate and tectonism. Whereas the northernmost basin margin shows no evidence of significant tectonic activity, the opposite is the case in the southeastern area where the interaction of faulting and sedimentation is marked. From the present results the basinwide Upper Rotliegend stratigraphic framework, based on tectonically-generated unconformities as established for the NEGB, has no validity for the northernmost margin.

OS04 : MOam02 : G8
Climate Stratigraphy: A Chronostratighraphic Reference Frame for Tectonically Active Basins (Late Miocene, SE Spain)

Thomas C. Brachert (tbrache@gwdg.de),
Uwe M. R. Krautworst, **Nadja Hultzsch** &
Andrea C. Knoerich
Institut fur Geowissenschaften, Becherweg 21, Mainz, D-55099, Germany

Climatic signals in Late Miocene shallow-water carbonates provide a high-resolution chronostratigraphic framework for the reconstruction of global sea-level fluctuations and synsedimentary tectonics. The Nijar-Carboneras basin represents a prototype for a Neogene intramontane basin of the Betic Cordillera of southern Spain. Its evolution is controlled by the Carboneras strike-slip fault and its conjugated fault systems. The substratum and Neogene sedimentary history of the subbasins to the north (Nijar) and to the south (Carboneras) of the fault is different and documents continuous, synsedimentary movements since the Tortonian (> 60 km of cumulative transport). Stratigraphic and facies architectures of the basin fill correspond with the movements of fault blocks, as expressed by angular unconformitites, neptunian dikes, autoclastic breccias and progradational patterns which mirror the structural framework. Tropical, transitional tropical/temperate, and temperate climatic stages documented in biofacies each bracket a certain amount of time during the Tortonian and Messinian and provide the basis for a high-resolution chronostratigraphy. Due to the strike-slip movements of the Carboneras fault, the present configuration of the basin was not achieved before the Late Pliocene, and differs significantly from the Miocene palaeogeography. Long-term strike-slip faulting has probably isolated also individual basins from the Mediterranean during the Late Miocene or perhaps the Mediterranean from the Atlantic during the Messinian salinity crisis.

OS04 : MOam03 : G8
Various Models of the Geodynamic Evolution and Paleogeography of the Carpathian Region

Andrzej Slaczka (slaczka@ing.uj.edu.pl) &
Jan Golonka
Jagiellonian University, Ul. Oleandry 2a, 30-063 Krakow, Poland

The several terranes form the mosaic of the tectonic units of the present day basement of major plates in the circum-Carpathian region. The Early Paleozoic rifting and drifting detached several terranes from Gondwana. These terranes collided with Baltica during the Caledonian orogeny (Late Ordovician Early Devonian) and the early stages of the Hercynian (Variscan) orogeny. Baltica at this time became the part of the larger continent Laurussia. During the Carboniferous time the Hercynian orogeny was concluded with the collision of Gondwana and Laurussia whereas the Tethys Ocean formed the embayment between the Eurasian and Gondwanian branches of Pangea. The Mesozoic rifting events resulted in the origin of the oceanic type basins like Meliata and Pieniny along the northern margin of the Tethys. Separation of Eurasia from Gondwana resulted in the formation of the Alboran-Ligurian-Pieniny Ocean as a part of the Pangean breakup tectonic system. Major plate reorganization happened during the Tithonian time. The Central Atlantic began to propagate to the area between Iberia and the New Foundland shelf. The Ligurian-Pieniny Ocean reached its maximum width and stopped. There are various models explaining the closing of the Pieniny Klippen Belt Ocean. 1. Subduction developed at the northern margin of the Inner Carpathian terranes. Latest Cretaceous-earliest Paleocene was the time of the closure of the Pieniny Ocean and the collision of the Inner Carpathians terranes with the Czorsztyn Ridge. The subduction zone jumped from the southern margin of the Pieniny Basin to the northern margin of the Czorsztyn ridge and began consume the Magura Basin. The Jurassic-Early Cretaceous Magura Basin was a part of the Mesozoic Tethyan oceanic system connected with Ligurian-Pieniny Ocean. The Silesian and other Outer Carpathian basins developed as rifts on the European margin. 2. Subduction developed at the southern margin of the Eurasian. The Outer Carpathian basin had developed as a back-arc. By the Albian time the part of the Pieniny Klippen Belt Ocean (Grajcarek-Hulina basin) was consumed and new Magura Basin has been developed. 3. Subduction developed at both margins of the Pieniny-Magura basin. The Outer Carpathian realm is a combination of oceanic (part of Magura) and continental rifted basins. The rifted subbasins, like Dukla, Silesian, Sub-Silesian, Skole, Tarcau, were separated by uplifted areas. Paleogene was the time of the closure of the Pieniny Ocean. The oblique collision of the Adria-Alcapa terranes with the North European plate led to the development of the accretionary wedge of Outer Carpathians and foreland basin. The formation of the West Carpathian thrusts was completed by the Miocene time. The thrust front was still progressing eastwards in the Eastern Carpathians.

OS04 : MOam04 : G8
Constraints on Himalayan Tectonic and Exhumation History Determined from the Kamlial Formation Foreland Basin Sediments, Pakistan

Yani Najman (y.najman@glg.ed.ac.uk)[1],
Malcolm Pringle (m.pringle@surrc.gla.ac.uk)[2],
Eduardo Garzanti (eduardo.garzanti@unimib.it)[3],
John Stix (stix@eps.mcgill.ca)[4],
Nicola White (nicola@esc.cam.ac.uk)[5] &
Imran Khan (imran@gsp.qta.sdnpk.org)[6]
[1] Dept of Geology, Edinburgh University, West Mains Rd, Edinburgh EH9 3JW, UK
[2] SUERC, Sottish Enterprise Technology Park, Rankine Ave, East Kilbride, G75 0QF, UK
[3] Dipartimento di Scienze Geologiche e Geotecnologie, Università di Milano-Bicocca, Piazza della Scienza 4, 20126 Milano, Italy
[4] Dept. of Earth and Planetary Sciences, McGill University, 3450 University Street, Montreal, Quebec, H3A 2A7, Canada
[5] Dept of Earth Sciences, Cambridge University, Downing St., Cambridge CB2 3EQ, UK
[6] Paleontology and Stratigraphy Branch, Geological Survey of Pakistan, Sariab Road, Quetta, Pakistan

Early stages of an orogen's exhumation history are often obscured in the mountain belt itself by later metamorphism, tectonism or erosion. Hence the sedimentary record, of material eroded from the mountain belt prior to later metamorphism and preserved in basins adjacent to the orogen, provides invaluable information on this early history.

In the foredeep, comparison of orogen-derived detrital white mica ages with the host sediment depositional age (determined by magnetostratigraphy) provides a method to identify periods of rapid exhumation in the orogen. Individual mica grains are dated using the ^{40}Ar-^{39}Ar isotopic method. These ages represent the timing of cooling through the mica closure temperature (~350ºC) during exhumation in the orogen. Times when the detrital mica age and the sediment depositional age are similar implies rapid orogenic exhumation at this time.

The pre-Siwalik Neogene orogen-derived sediments in the Himalayan foredeep consist of, in Pakistan, the Kamlial Formation, magnetostratigraphically dated at 18-14 Ma (Johnson et al. 1985), and in India, the Dharamsala Formation, aged 20-11 Ma (Burbank & Maithani, unpublished data). White et al. (1999) first validated the technique on the Dharamsala Formation, India, documenting rapid exhumation of garnet-staurolite grade Tertiary metamorphic rocks of the High Himalaya at ~20 Ma, which corresponds with the known period of exhumation associated with movement along the South Tibetan Detachment Fault.

Our current work on the Kamlial Formation, Pakistan, shows that in sediments aged 17-18 Ma, the youngest micas are 23 Ma, implying an averaged cooling rate of >50ºC/Ma for this period. Sediments aged 15-16 Ma contain micas dated 16-17 Ma, implying extremely rapid exhumation at this time. Sediments deposited at 14 Ma have a distinctly different mica population: all micas are older than 30 Ma and >80% of grains are aged 200-450 Ma (compared to <15% in the older samples). Additional analyses currently being undertaken will refine this data further.

Petrographic data from the Kamlial Formation indicate that for the majority of the samples, detritus is predominantly (≥ 2/3) derived from arc / suture zone rocks. Detritus includes arc-derived volcanic lithics and plagioclase, plus material from accreted oceanic rocks and obducted ophiolites including shale, slate, pelagic limestone, chert, metachert, metabasite, serpentine grains and spinel. Detritus from very low- to low-grade metamorphic rocks (quartz, feldspars and metapelite to metafelsite lithics) is subordinate (≤ 1/3). Most probable source rocks are the Kohistan Island Arc and Indian margin metamorphic rocks, which are separated by the Main Mantle Thrust and associated ophiolitic melange.

We use these data to document tectonic events and constrain the timing of fault movement in the orogen in Pakistan. Comparison with data from the co-eval Dharamsala Formation in India will indicate the extent of along-strike variation.

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OS04
Tectonics and Sedimentation

OS04 : MOam05 : G8
The Age of the Oldest Recorded Himalayan Foredeep Continental Sediments: Implications for the Orogen's Evolution

Yani Najman (y.najman@glg.ed.ac.uk)[1],
Malcolm Pringle (m.pringle@surrc.gla.ac.uk)[2],
Laurent Godin (lgodin@sfu.ca)[3] &
Grahame Oliver (gjho@st-andrews.ac.uk)[4]
[1] Dept of Geology, Edinburgh University, West Mains Rd, Edinburgh EH9 3JW, UK
[2] Scottish Universities Environmental Research Centre, Scottish Enterprise Technology Park, Rankine Avenue, East Kilbride, G75 0QF, UK
[3] Dept of Earth Sciences, Simon Fraser University, Barnaby, BC, V5A 1S6, Canada
[4] Crustal Geodynamics Group, School of Geography & Geosciences, Purdie Building, The University, St. Andrews, Fife, KY16 9ST, UK

The Balakot Formation foreland basin sediments, located in the Hazara-Kashmir syntaxis, Pakistan, consist of a >8 km thick succession of Himalayan-derived clastic red beds and calcrete, interpreted as deposited in a tidal environment. Within this sequence are intercalated four distinct grey fossiliferous marl and silt units, 20-60 m thick, dated at 55-50 Ma (Bossart & Ottiger 1989). Thus the Balakot Formation has been interpreted as the oldest continental foreland basin deposits; more than 20 My older than the earliest continental foredeep sediments deposited elsewhere in the basin. The timing of initiation of continental foredeep sedimentation, and the anomalously old age of the Balakot Formation compared to the earliest continental sediments along strike in the basin, has influenced models of the timing and degree of diachroneity of collision, mechanisms of orogenic exhumation, the timing of uplift, and foreland basin evolution.

We dated more than 250 detrital single white mica crystals from the Balakot Formation by Ar-Ar total fusion and step-heating techniques. The data shows a large population of micas aged ca 30-45 Ma, with a peak at 37 Ma. Since a detrital mineral age cannot be younger than it's host sediment depositional age, it is clear that the mica ages and biostratigraphic ages of 55-50 Ma deduced from the fossiliferous marl units are incompatible. One explanation for this apparent discrepancy could be that the mica ages do not represent cooling ages in the source area; instead they have been reset by later metamorphism subsequent to deposition in the foreland basin or have been subjected to alteration. However, a number of tests, including step-heating experiments and petrographic, illite crystallinity and electron probe studies indicate that alteration and resetting are insignificant.

Bossart and Ottiger (1989) mapped the Balakot Formation in the Kaghan valley as a steeply north-dipping, homoclinal, normal stratigraphic succession. However, detailed mapping revealed that the Balakot Formation is intensely folded, with the fossiliferous marl bands outcropping near the core of anticlines or high-strain zones. We therefore argue that the marl units are part of an underlying formation, exposed by subsequent deformation and therefore cannot be used to date the continental red beds of the Balakot Formation. Thus, the geology is consistent with detrital mica ages that show that the Balakot Formation is younger than Early Oligocene age, and therefore models of the timing and diachroneity of collision, exhumation mechanisms and foreland basin processes which are influenced by the previous age determination of the Balakot Formation need to be re-evaluated.

Bossart P & Ottiger, R., *Eclogae Geologica Helvetica*, **82**, 133-165, (1989).

OS04 : MOam06 : G8
Exhumation and Sedimentation – The Example of the Central Alps: I. Ar/Ar Geochronology and Chemistry of Detrital White Mica

Hilmar von Eynatten (eynatten@geo.uni-jena.de)[1] & **Jan R. Wijbrans** (wijj@geo.vu.nl)[2]
[1] Institut fuer Geowissenschaften, Burgweg 11, D-07749 Jena, Germany
[2] Faculty of Earth Sciences, De Boelelaan 1085, NL-1081 HV Amsterdam, Netherlands

Geochronology of detrital minerals from foreland basins has become a powerful tool to constrain cooling and exhumation history of modern and ancient orogens. Variations of cooling rates and pattern in the orogen through space and time are documented in the sedimentary record. Precise chronostratigraphic calibration of the sediments and detailed knowledge on sediment provenance are major prerequisites for tracing differential cooling of the hinterland. The Central Alps and the Swiss Molasse Basin represents an ideal case study to link the results derived from geochronology of the detritus to the results derived from geochronology of the still exposed hinterland.

We have seperated white mica from sandstones of six major depositional systems covering the Swiss Molasse Basin from Lake Geneva in the west to Lake Constance in the east. Samples range stratigraphically from Lower Oligocene (31 Myr) to Middle Miocene (13 Myr). Mica from the easternmost alluvial fans display exlusively Variscan cooling ages (270 -340 Myr) except for rare Cretaceous ages in a 29 Myr sandstone. Mica from the central alluvial fan system display a much more differentiated age pattern. Mica from sandstones older than about 20 Myr display again exclusively Variscan cooling ages (260-350 Myr) except for rare Jurassic ages in a 31 Myr sandstone. Mica from sandstones younger than 20 Myr show increasing proportions of Tertiary cooling ages. This change in ages is accompanied by a change in white mica chemistry from exclusively muscovite to increasing proportions of phengite. Calculated average cooling rates increase continuously from <20°C/Myr at 20 Myr to around 35°C/Myr at 14 Myr. Mica from the westernmost deposits also display mostly Variscan cooling ages but again first Tertiary mica ages occur in about 20 Myr old sediments. Generally, the amount of mica with Cretaceous cooling ages is extremely low.

The following conclusions are drawn: (1) Oligo/Miocene Central Alpine source rocks were not affected by Cretaceous metamorphism >300°C. (2) Based on the Oligo/Miocene sediments increasing cooling rates of the hinterland are observed for the same time slice for which a major phase of exhumation of the Lepontine metamorphic dome ist postulated based on work in the present-day orogen. This observation is restricted to the part of the foreland basin directly facing the exhuming metamorphic dome. Thus, the Central Alpine cooling history as deduced from detrital minerals of the Swiss Molasse Basin strongly resembles the cooling/exhumation history deduced from presently exposed rocks in the Central Alps. (3) Our study proves detritus geochronology to precisely mirror tectonic processes of the hinterland and thus underline the potential of the method for case studies where the hinterland is no longer accessible.

OS04 : MOam09 : G8
A Provenance Study of a Post-Collisional Transgressive Sequence (Molare Formation, Italy) through Integrated Facies Analysis, Mineral Chemistry and $^{40}Ar/^{39}Ar$ Dating

Chiara Barbieri (chiara.barbieri@manhattan.unipv.it)[1],
Barbara Carrapa (carb@geo.vu.nl)[2],
Andrea Di Giulio (digiulio@unipv.it)[1] &
Jan Wijbrans (wijj@geo.vu.nl)[2]
[1] Dipartimento di Scienze della Terra, Università di Pavia, via Ferrata 1, 27100 Pavia, Italy
[2] Faculteit der Ardwetenschappen, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands

The Molare Fm. constitutes the Oligocene base of a transgressive sequence deposited on crystalline basement belonging to the Ligurian Alps. Facies analysis, electron microprobe analyses on phengites, anphiboles and garnet, and $^{40}Ar/^{39}Ar$ dating on white micas have been applied in order to define the source area and distribution pattern of the first basin infill.

Facies analysis was carried out in order to recognize environmental changes, which potentially could have affected sedimentary transport mechanisms and directions (fluvial vs. shallow marine, transversal vs. long-shore). The studied samples came from both the Molare Fm. and the two crystalline basement complexes underlying it (Voltri massif in the NE and Brianconaise units in the SW). Microprobe chemistry and $^{40}Ar/^{39}Ar$ ages on white micas provide the best data, allowing the division of the study area into two sectors, which directly mirror the substratum of the transgressive sequence. The NE sector is characterized by a main age family of 50 ±10 Ma and corresponding phengite celadonite contents of Si 3.4-3.7 a.p.f.u. suggesting a provenance from high pressure rocks such as metasedimentary units of the Voltri Group. The SW sector is characterized by Varisican ages around 270 - 300 Ma and corresponding lower phengite celadonite contents of Si < 3.2 a.p.f.u. suggesting a provenance from the Briançonaise basement.

Amphiboles allow further provenance distinctions within each sector. In particular, they highlight the heterogeneous metamorphic evolution of the Voltri Group source, as alkali-amphiboles occur mainly in the north, where rocks were faintly affected by retrograde metamorphism, whilst calcic and alkali-calcic minerals occur in the south, where retrogression was stronger. Glaucophane is the only amphibole occurring in the SW samples, probably fed by the Bagnaschino unit (blueschists facies) or Pamparato-Murialdo unit and Calizzano-Savona Massif (glaucophane-bearing greenschists facies).

Garnets mainly occur in samples from the NE sector suggesting a provenance from the Voltri Group. Their signal though is not distinct enough to recognize specific source rocks within the massif.

As a whole, mineral chemistry and geochronology, reflects local basement of the Molare Formation, suggesting no significant long-shore drift or mixing occurred during transgression. Furthermore among different techniques, $^{40}Ar/^{39}Ar$ on white micas result to provide the most clearly correlating data between source area and basin infill. This study gives the basis for detecting the source evolution of younger post-orogenic sediments, less directly linked to their source.

OS04 : MOam10 : G8
Excimer Laser ICP-MS Dating of Zircons from Earth's Major Rivers: Preliminary Results from North America

Kenneth Eriksson (kaeson@vt.edu)[1],
Ian Campbell (ian.campbell@anu.edu.au)[2],
Michael Palin (michael.palin@anu.edu.au) &
Charlotte Allen (charlotte.allen@anu.edu.au)
[1] Department of Geological Sciencesical Sciences, Virginia Tech, Blacksburg, Virginia 24061, USA
[2] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia

A method has been developed for quality dating of zircons by excimer laser ICP-MS that allows over 200 grains to be dated in a ten hour day. The method is ideal for rapid analyses of large numbers of detrital grains and is being used to date zircons from Earth's major rivers. Analyses of standard zircons give one sigma errors for individual grains of ±15 Ma at 1850 and ±6 my at 572 Ma. The principal aim of this project is to use detrital zircons to recognize Earth's major tectono-magmatic (crustal melting) events and to test whether the events are periodic or random. The study will also provide a number of valuable bi-products including: (i) time scales for the Earth's major orogenic and anorogenic events, (ii) data that can be used to test suspect terrain hypotheses, (iii) information about the source of material that is eroding into modern rivers and how human activity affects erosion patterns, and (iv) geomorphological applications such as documenting previous river courses and river captures.

Our pilot study focuses on North American rivers east of the Rocky Mountains because the bedrock geology in these river catchments is well understood. To-date, ~1000 zircons have been analysed from the Susquehanna, Potomac and James rivers that drain eastwards into the Atlantic Ocean, the New River that flows westwards from the Appalachians, and the Ohio, Missouri and Mississippi rivers. Rivers that drain the Appalachian Mountains are strongly dominated by Grenville-age zircons and show a slow build up from ~1350 Ma followed by rapid fall off in magmatism at ~1000 Ma. The Penobscotian orogenic event (510-470 Ma) is well represented in the east coast rivers but evidence for pre-Grenville and younger Appalachian orogenic events is sparse. Zircons in the New and Ohio rivers are also mostly of Grenville age. A lack of Archaean zircons in the Ohio River mitigates against a glacial contribution to the sediment load. The Mississippi River, north of the confluence with the Missouri and Ohio rivers, is dominated by Archaean (2500-2800 Ma), Penokean (1900-1800 Ma), and Grenville zircons as well as ~1500 Ma anorogenic components. Similar age populations are present in a loess deposit from Wisconsin to the north suggesting that glacial processes have contributed significantly to the sediment load of the Mississippi River. A distinctive characteristic of the Missouri River is a strong late Cretaceous-early Tertiary population provisionally attributed to magmatism in Idaho. Other zircon populations in the Missouri River reflect erosion of the Archaean

Wyoming (2500-3000 Ma) and Penokean/Trans Hudson (2000-1800 Ma) provinces as well as ~1500 Ma anorogenic components. A Mississippi River sample from south of the confluence with the Missouri and Ohio rivers records the mutiple tectono-magmatic events of the larger catchment area.

OS04 : MOam11 : G8
Nd-Isotope Systematics of Lower Palaeozoic Sediments from Eastern Avalonia: Precise Monitoring of Magmatic and Orogenic Activity

Axel Gerdes (ager@bgs.ac.uk)[1],
Timothy C Pharaoh (tcp@bgs.ac.uk)[2],
Timothy Debacker (timothy.debacker@rug.ac.be)[3],
Jacques Verniers (jacques.verniers@rug.ac.be)[3] &
Stephen R Noble (srn@nigl.nerc.ac.uk)[1]
[1] NERC Isotope Geosciences Laboratory, Keyworth, NG12 5GG, UK
[2] British Geological Survey, Keyworth, NG12 5GG, UK
[3] Laboratorium voor Paleontologie, Krijgslaan 281/S8, B-9000 Ghent, Belgium

Source areas of clastic sediments, and therefore also their isotope composition, change during orogenic evolution. Nd isotope signatures are controlled by detrital components supplied by continental erosion and volcanic activity. We present Sm-Nd data of Ordovician and Silurian sediments from the Brabant Massif, in the southern part of the Anglo-Brabant Basin, which is part of the Eastern Avalonian microcontinent. Our results and published data (André et al., 1986, Thorogood, 1990, André, 1991) show remarkably similar Nd isotope trends of Eastern Avalonian Lower Palaeozoic sedimentation (Ardennes, Anglo-Brabant Basin and Welsh Basin). In the Lower to lower Middle Cambrian deposits $\varepsilon Nd_{(T)}$ values decrease from about -3 to -8.5 or up to -10. After a short increase during Middle and Upper Cambrian transgression $\varepsilon Nd_{(T)}$ drops again from -7.5 to -9 towards the Lower Ordovician. This reflects decreasing influence of juvenile material from Avalonian-Cadomian magmatic arcs and increasing input of unradiogenic detritus from the Gondwana hinterland. During mid-Tremadoc to Upper Caradoc (c.490 to 458 Ma) Nd isotopes define a zig-zag curve caused by the repeating supply of juvenile, volcanogenic detritus. $\varepsilon Nd_{(T)}$ values jump from around -9 to about -5 to -7 on three occasions, suggesting contemporaneous magmatic activity at upper Tremadoc/lower Arenig (c.485 Ma), upper Arenig (c.475 Ma) and mid-Llanvirn (c.465 Ma) due to phases of subduction in the Iapetus and Tornquist Oceans, leading to the northward drift of Avalonia. Although mid-Caradoc magmatism (~455 Ma) is present in the Brabant Massif, such detritus is only documented in contemporaneous Welsh sediments. From late Caradoc to late Llandovery (c.452 to 430 Ma) the $\varepsilon Nd_{(T)}$ values in the entire area gradually increase from -9 to -6 or -5, possibly reflecting the erosion of uplifted Avalonian arcs during oblique collision with Baltica. In addition, juvenile detritus was supplied by Ashgillian-early Silurian volcanism. During Silurian turbiditic sedimentation the $\varepsilon Nd_{(T)}$ progressively decreases over ~10 Ma to about -9.5 in the uppermost Ludlow. This voluminous, often laterally very continuous sedimentation at the Avalonian margin, is caused by accelerated subsidence during foreland basin development (VanGrootel et al., 1997). From the Llandovery onwards the Windermere Supergroup (Lake District) shows an identical Nd isotope trend (McCaffrey, 1994). This uniform drop in $\varepsilon Nd_{(T)}$ can be correlated with the cessation of subduction and a continuously increasing amount of old continental detritus due to the final collision of (Avalonia-)Baltica with Laurentia forming the Scandian Orogen. Therefore, $\varepsilon Nd_{(T)}$ used as tracer suggests that the east Avalonian basins belonged to the same palaeogeographic entity from Cambrian to Devonian time with only a minor supply of locally different detritus. Despite the evidence for a juvenile Neoproterozoic basement (Noble et al., 1993), Nd isotopes of Avalonian sediments repeatedly are untypically unradiogenic, indistinguishable from some Baltic or Laurentian $\varepsilon Nd_{(T)}$ signatures.

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OS04 : MOam12 : G8
Geochemical Provenance Indications of Pre-Andean Sediments in Southernmost Chile (47° to 51° S): Implications for a Continental Tectonic Setting

Carita Augustsson (augustss@uni-muenster.de),
Heinrich Bahlburg & **Nicole Dobrzinski**
Geologisch-Paläontologisches Institut, Corrensstrasse 24, D-48149 Muenster, Germany

A provenance study of the Late Paleozoic to Early Mesozoic metasedimentary 'basement' of the Andes in easternmost southern Chile indicates a continental tectonic setting for the source rocks. The "basement" is principally composed of low-grade metamorphic Devonian to Permian sedimentary rocks, dominated by turbidites. These are usually strongly deformed, due to their position in an Early Mesozoic accretionary wedge. Since the sandstone parts of the turbidites have a high matrix content, whereas the clasts mainly constitute of quartz and feldspar grains, the rocks are classified as greywackes. They are, with CIA values between 59 and 66 for calcite free samples, only moderately altered. CL images reveal both quartz with plutonic and metamorphic origin, where later metamorphism has not overprinted the original characters. Major elements indicate a primary felsic source rock composition for most samples, but an intermediate felsic-mafic rock composition for a group of samples in the southern part. REE values are similar to, or slightly lower than, PAAS (Post-Archean average Australian shale) and UCC (upper continental crust) values. Eu/Eu* values (in general 0.6-0.9) are close to, or slightly higher than, estimated values for both UCC and PAAS, reflecting the feldspar content. Zr/Sc and Hf/Sc values (mean values 30 and 1.0 respective) are reflecting enrichment of zircons by sorting during transportation, and a potential influence of recycling. La/Sc and Th/Sc values are generally close to, or higher than, UCC values, wherease Th/U and La_N/Yb_N values in general are slightly lower than UCC values. The petrography indicates mainly a continental block provenance, with both primary and recycled material, for the sediments. The chemical data, including combinations of La, Sc, Th, Co and Zr values, give further indications of silicic source rocks from a continental setting. The southern sediment samples, with the less felsic composition, are indicated to derive from an arc environment.

OS04 : MOam13 : G8
Major Trends in Caledonian Volcanic Activity Derived from Metabentonites of the Baltic Basin

Vykintas Motuza (vykintas@geologin.lt),
Saulius Sliaupa (sliaupa@geologin.lt) &
Jevlampijus Lashkovas
Institute of Geology, Shevchenkos 13, Vilnius, Lithuania

The Baltic basin represented the marginal basin onlapping western periphery of the East European craton during Cambrian-Silurian times. Numerous metabentonites (MB) are documented in the Ordovician-Silurian carbonate-shaly succession of the basin, thus reflecting volcanic activity in surrounding Caledonides. Closest to the North German-Polish Caledonides the MB are mapped throughout the whole Ordovician section, while they are confined to only Arenigian, Lower-Middle Caradocian (most voluminous) and Ashgillian intervals further east. Lateral distribution of MB indicates transportation of volcanic ash from the W and NW sources. Occurrence of MB sharply increases in the Lower Silurian and are only scarce in the Upper Silurian. Mineral composition is dominated by mix-layered I-S, kaolinite composes 0-60%. REE and trace element composition of MB was studied seeking to reconstruct parent lithologies and their tectonic setting. It revealed dominant felsic composition of source rocks. Caradocian MB show affinity to dacites and rhyolites, while the Ashill bentonites resemble trahyandesites. This suggests maturation of volcanic systems in time. Silurian MB were likely sourced from dacites and trahyandesites. Trace element chemistry indicates 2 distinct sources of the Lower Caradocian MB with dominating calc-alkaline and less prominent tholeiitic trends. The M.Caradocian also show double sourcing, yet tholeiitic trend gives way to transitional one. Ashgill ianand Silurian MB show calc-alkaline chemistry. Trace elements point to general trend towards more acid parent lithologies from Lower Caradocian to Ashgillian and Silurian. Syn-collisional tectonic setting was suggested from geochemical composition of Ordovician-Silurian MB. Geochemical features imply continental type of volcanic arcs, though some L.Caradocian and Silurian samples show oceanic setting. Geochemical features of Baltic MB indicate evolved character of volcanic arcs that developed along the converging margins of E.Avalonia, Baltica and Laurentia during Ordovician-Silurian, showing some maturation trend in time. Majority of volcanic ash was sourced from continental volcanic arcs. Yet, some Lower Caradoc MB are products of oceanic arcs that matured in Middle Caradoc. Also, some Silurian MB show derivation from subduction of primitive (oceanic) crust besides the dominating mature continental volcanoes.

OS04 : MOam14 : G8
Measuring Pb and Ar Isotopes on the Same Material: A Tool for Provenance Evaluation

Peter Copeland (copeland@uh.edu)[1],
Matthew Evans (mje7@cornell.edu)[2] &
Louis Derry (derry@geology.cornell.edu)[2]
[1] Dept. of Geoscience, Univ. of Houston, Houston, Texas 77204-5503, USA
[2] Dept. of Geol. Sci., Cornell University, Ithaca, NY 14853, USA

When evaluating the tectonic evolution of a mountain belts, questions of interest include: What rock types were exposed as the orogen evolved and it what abundance? and over what intervals and at what rates were these rocks brought to the surface? In the case of the past evolution of an orogen, it is difficult to answer questions about rocks which no longer exist but this information may be contained in the isotopic composition of detrital grains. The Pb isotopic composition is one potential tracer of the type of rocks in the source area and the $^{40}Ar/^{39}Ar$ age of grains is a reflection of their thermal history. Both of these approaches have been applied to sands and sandstones derived from orogenic belts; we present here a test of applying both techniques to the same grains.

We have taken ~0.5 mm grains of sanidine from the Fish Canyon Tuff and split them into two groups for Pb isotope analysis by ICP-MS. Three untreated grains had average $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ of 0.84436±0.00125 and 2.04166±0.00319, respectively. Five grains which were irradiated for 20 hours (a typical duration in $^{40}Ar/^{39}Ar$ analysis) and subsequently fused into small glass beads using a 10 W CO_2 laser had average $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ of 0.84589±0.00238 and 2.04771±0.00376, respectively. These two data populations are statistically indistinguishable at the 95% confidence level (students t-test). These results suggest that the procedures typically used in $^{40}Ar/^{39}Ar$ analysis of detrital grains do not fractionate Pb isotopes.

Results documenting the relationship between minimum $^{40}Ar/^{39}Ar$ age and Pb isotopes in K-feldspars from the Jhelum River in NW Pakistan will be presented.