EUG XI

Symposium RCM3

Contrasting Processes of Continental Rift and Passive Margin Development: Comparison of Results from the Modern Oceans and Orogenic Belts

Convenors

Alastair Robertson
H.-C. Larsen
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Tuesday PM Session

RCM3 : TUpm25 : F3
Deep Seismic Reflection and Refraction Study of the Angola-Congo Margin

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In March-April 2000, a regional marine seismic reflection and refraction survey has been acquired on the Angola-Congo passive margin within the Zaiango (Zaïre - Angola) project conducted in collaboration between Ifremer and Elf Exploration Production. The aim of this cruise was to image the deep structures of the Angola-Congo margin in order to understand processes of extension and the lateral transition from a segment of margin to another one.

For the acquisition, we use a 'single bubble' air gun array (Avedik, 1993) synchronised on the first bubble pulse, instead of the initial pulse in order to concentrate the energy in the 10-20 Hz bandwidth. Seismic reflexion data were combined with OBS (Ocean Bottom Seismometer) data to get both the images and the velocity structure of the deepest part of the margin, beneath the salt layer.

Preliminary results confirm the existence of a thick upper Jurassic-lower Cretaceous basin already emphasized from gravity data. The transition from continental to oceanic crust and the associated west dipping reflector (SDR's ?) as well as east dipping reflectors within the oceanic crust above the well-defined oceanic Moho were clearly imaged.

Avedik F, Renard V, Allenou JP, Morvan B, *Geophysics*, **58**, 366-382, (1993).

RCM3 : TUpm26 : F3
Deep Structure of the Angola Margin from Wide-Angle Reflection/Refraction OBS and Multi-Channel Seismic Data

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An air gun array operated in single bubble mode (Avedik et al, 1993) was used during the ZaïAngo deep seismic cruise that surveyed the South Atlantic margin of Angola. The cruise was conducted in collaboration between Ifremer and Elf Exploration Production. Marine shots were recorded by land seismometers and offshore by an OBS network and the 360 multi-channel seismic (MCS) streamer of Ifremer. The OBS wide-angle reflection / refraction data have been interpreted by using the ray tracing program of Zelt and Smith (1992). The shallow part of the model was built using the geometry coming from the interpretation of MCS lines. The deep part of the model was constrained by OBS data. On the eastern part of the margin, a deep subsalt basin (about 15 km depth) is underlain by a body with a velocity of 7.2 to 7.5 km/s at about 20 km deep. Despite the disturbance and complexity brought by salt tectonics, the simultaneous study of the multichannel seismic profiles and OBS allow to propose a well constrained crustal model of the Angola Margin.

Avedik, F., V. Renard, J-P. Allenou and B. Morvan, *Geophysics*, **58**, 366-382, (1993).
Zelt, CAand RBSmith, *Geophys. J. Int*, **108**, 16-34, (1992).

RCM3 : TUpm27 : F3
2D Lithospheric Structure across the Variscan Iberian Belt and the SW Iberian Continental Margin

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We present a 2D lithospheric cross-section which strikes from the central Iberian Peninsula to the African margin crossing the entire Variscan Iberian belt and the SW Iberian continental margin until the African plate. The area is characterized by the presence of different Hercynian geotectonic units with contrasted crustal nature, the progressive thinning of the Iberian Massif towards the SW margin, the continental-oceanic transition that coincides with the African-Eurasian plate boundary, and the oceanic domain of the African plate. Forward modelling has been performed using a finite element code that integrates heat flow, gravity, absolute elevation and geoid data under considering thermal steady state and local isostasy. Seismic data have been used where available to constrain the crustal structure. In the emerged section, the results show a 30 km thick crust characterised by a relatively thick and dense (17 km, 2800 kg/m^3) intermediate layer in order to fit the large measured Bouguer anomaly. Also, we find differences in the crustal nature of the South-Portuguese Zone and the Ossa Morena and Centro-Iberica Zones. Towards the margin the Moho rises from 30 km to 12-13 km in the ocean-continent transition. Further to the SW, well in the oceanic domain, the Moho lies at about 13 km. The base of the lithosphere is placed at 115 km below the Variscan Iberian Massif showing a dome-shaped thinning below the Ossa Morena and South Portuguese zones. The lithosphere thickens again below the margin and the African plate showing thickness of 100 km and 108 km, respectively. The origin of this dome-shaped thinning can be attributed to either deep tectonic Neogene processes related to the Alboran-Betic-Rif system, or to a mass deficiency placed at the base of the lithosphere and related to a mantle depletion process occurred during the Hercynian collision.

RCM3 : TUpm28 : F3
The Mid-Norway Atlantic Margin: Deep Structures According to Industry Seismic Data

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Through an ongoing project ('BAT') at the Geological Survey of Norway, subsurface data from the Mid-Norway shelf were acquired in order to address the deep structure and regional tectonics of the Norwegian Sea. A key area of focus has been to establish the transition from the onshore to the offshore geology. The Mid-Norway shelf, located between 62ºN and 68ºN is limited by the Møre-Trøndelag Fault Zone in the SE and the Møre and Vøring Marginal Highs to the NW. Structures and normal faults are oriented NE-SW or N-S, while major fracture zones and lineaments are oriented NW-SE. Subsurface data set consists of seismic lines from a deep (down to 14 seconds Two Way Travel) commercial survey and wells tied to the seismic grid. Tertiary to Jurassic sedimentary units are well-imaged. However, these packages have been the focus of industry interpretations during the last decade and we have instead chosen to focus on the deeper crustal units and related architecture. In the southern area of the studied offshore, the seismic profiles highlight rotated blocks displaying Permo-Triassic and possibly older age sediments constrained by well data. These blocks are onlapped by Triassic, Jurassic or younger units, deposited in half-grabens structures. Blocks and half-grabens are associated with low-angle normal faults which merge into a major detachment zone at 9-10s TWT, interpreted as strongly sheared basement rocks. The transition from the Trøndelag Platform to the Vøring Basin is marked by a major fault (Klakk Fault Complex). The N-S orientation of this fault is oblique to the NE-SW major trend of the dominant structural grain, suggesting reactivation of previous structures. Large displacement is observed along this fault (c. 40 km) and activity ceased at the Early Cretaceous. On the other side, the northern area of the offshore is characterized by a flexure rather by a large-magnitude extensional fault. Jurassic and Early Cretaceous strata appear to onlap a NW-dipping surface interpreted as the top of a deep-seated, rotated fault block. In conclusion, data suggest a major orientation change from a W- to NW- dipping normal fault in the S to a SE-dipping normal fault in the N. A shift of polarity is induced along the basin. Transition from offshore to onshore data is completed by nearshore seismic data (down to 3s). The profiles show previously described Jurassic half-grabens, but the high penetration of the data highlights the entire geometry of the basins.

RCM3 : TUpm30 : F3
The Mid-Norway Atlantic Passive Margin

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We will discuss several issues and new insights into the structure and dynamics of the Mid-Norway passive margin evolution. For the first time, we present here a consistent onshore-offshore structural model from present-day to Late Permian for the development of the conjugate margins of Greenland and Norway. We focus on the post-Late Permian extensional history of Mid-Norway, following the latest orogenic spasms and the development of the Devono-Carboniferous intra-orogenic basins and the foreland deep. Several topics will be addressed:
- the present-day extent and the position of the innermost normal fault
- the rift border fault (RBF)
- separating the extended passive margin from the unaffected continent. The RBF is formed in Mid- and Western Norway by the LGFZ/Åre-Røragen fault zone, located W of the present-day Caledonian thrust front.
- the position of the continent ocean boundary (COB) and the outermost continental blocks, the Vøring/Møre marginal highs. The width of the passive is measured between the innermost normal fault and the COB;
- normal faults associated with continued polyphase rifting since Late Permian: implications on original morphology, topography, and paleogeography;
- crustal-scale cross-section showing the continuous onshore/offshore structure of the passive margin;
- crustal scale cross-sections of the conjugate Greenland-Norway passive margins showing the asymmetric nature of the crustal extension. Further, the upper plate/lower plate geometry and the dip of the major extensional normal faults change across the Jan Mayen Transform. South of the transform in the Møre Basin (Norway) and in the Jameson Land area (Greenland) the dip is towards the W, whereas north of the transform in the Vøring-Trøndelag area (Norway) and in the Traill Ø-Hold With Hope-Wollaston Foreland area (Greenland) the major faults dip to the East. The structure of the transition zone is shown on pre-breakup plate reconstruction for anomaly 24 (53 Ma), together with the breakaway line of the future North Atlantic Ocean. Rather than a clear-cut transition, we show that there is a progressive change of vergence of normal faults between the Vøring-Trøndelag area and the Møre Basin along the Mid-Norway coast. The change in geometry occurs along the Helland Hansen zone, and there is no evidence, nor need, for a crustal fracture zone. - plate-tectonic reconstructions consistent with continuous rifting from Permian to present-day. Changes in extension directions during time are coherent with basin development and major periods in plate dynamic reorganisations.

RCM3 : TUpm31 : F3
The East Greenland Caledonides – A Typical Rifted Continental Margin?

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In 1990 and 1994 a combined marine-land seismic refraction survey was undertaken in East Greenland by the Alfred Wegener Institute for Polar and Marine Research. Several profiles were acquired in the long fjords across the East Greenland Caledonides and the passive rifted margin. Conventional interpretation including the ray tracing modelling of P-wave travel times in combination with magnetic and gravity data has been performed (Fechner and Jokat, 1996; Mandler and Jokat, 1998; Schlindwein and Jokat, 1999).

In this contribution additional shear wave ray tracing as well as finite difference waveform modeling will be introduced. This provides further constraints on the crustal structure within the region investigated. Kinematic ray tracing includes S-wave velocity-depth models and the calculation of Poisson's ratio. The models show a fairly homogeneous velocity distribution in the upper and middle crust with Poisson's ratio varying between 0.22 and 0.30. The dynamic FD full elastic wavefield modeling has been used to better understand crustal phases and Moho reflections. Snapshots and synthetic seismograms as well as amplitude considerations help to distinguish regions with a high-velocity layer which is interpreted as Tertiary magmatic underplate.

The latest results from 3D gravity modeling for the East Greenland Caledonides and the adjacent eastern and northern shelf region will be presented. This leads to the estimation of sediment and crustal thickness at certain locations as well as basin extensions. Compilations containing sediment distribution and Moho depth show the current status of interpretation. The crustal structure of the East Greenland passive rifted margin will be compared to the conjugate Scandinavian Caledonide region.

Fechner Nand Jokat W, *J. geophys. Res*, **101**, 15867-15881, (1996).
Mandler Hand Jokat W, *Geophys. J. Int*, **135**, 63-76, (1998).
Schlindwein Vand Jokat W, *J. geophys. Res*, **104**, 7527-7537, (1999).

RCM3 : TUpm34 : F3
Variations of Vertical Movements along the Corinth-Patras Rift (Greece): A Possible Influence of the Western Hellenic Subduction Zone

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The E-W trending Corinth-Patras rift is the major transverse structure crossing the Hellenic arc. Geodesy shows that the N-S extension rate increases from 0.5 cm/yr in the east of the rift (Corinth), to 1.5 cm/yr in the west (Aigion). The active normal faults of this asymmetric graben trend E-W off the southern shore of the gulf and dip to the north. They control the subsidence of the gulf in their hanging wall, and the uplift of northern Peloponnese in their footwall. Uplift rate along the Peloponnesian coast is determined using uplifted marine terraces, holocene notches or archaeological data. It increases from 0.3 mm/yr in the east of the gulf to 3 mm/yr in the west. This increase could result from a greater slip rate on the normal faults, related to the higher extension rate toward the west. In this hypothesis, subsidence of the gulf north of the faults should also increase toward the west. The subsidence of the gulf is poorly constrained, due to a lack of geophysical data about the sediment thickness, and the depth of their basis. However, bathymetry shows a maximum water depth of some 900 m in the eastern gulf, and a decrease to 60 m in the west (Rion strait). This decrease of subsidence toward the west disagrees with the increase of the extension rate.

In the west, the low subsidence of the gulf and the strong uplift of Peloponnese suggest that a more general uplift is superimposed to the vertical motions caused by normal faulting. Indeed, the rift cuts across the overriding lithosphere of the Aegean subduction zone, and the regional scale variations of the vertical movements which are evidenced may be related to the geodynamics of the arc. The western end of the rift overlies an about 50 km thick crustal root, which trends NNW-SSE beneath the uplifting mountain range of the external arc. This root may grow by underplating in the subduction zone between the two plates, and cause an isostatic uplift of the western area. Near Corinth, the eastern end of the gulf crosses the NNW-SSE trending Aegean volcanic line. There, the asthenospheric wedge mechanically separates the two plates.

The longitudinal variations of uplift or subsidence rates recorded along the Gulf of Corinth cannot be explained only by variations of the extension rate along the rift. They may reflect in the west the mechanical coupling with the subducting plate, with an uplift located above the thickening crustal root of the external Aegean arc.

RCM3 : TUpm35 : F3
Geodynamic Controls on the Cenozoic-Pleistocene Development of the Southern Upper Rhine Graben

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The NNE-SSW trending Upper Rhine Graben (URG) initiated in the Late Eocene as part of the West European rift system. This period of E-W extension in the foreland coincided with the peak of alpine collision to the south. Rifting was accompanied during the Oligocene and early Miocene by vertical motions of the basin and of its shoulders (Vosges and Black Forest).

In order to discriminate between vertical motions related to the rifting process and vertical motions related to the northward migration of the alpine forebulge, we reconstruct the Cenozoic evolution of the southern part of the graben and of its shoulders. Subsidence curves are drawn for the basin and a 3D model is constructed with the gOcad geometric modelling package. The model includes stratigraphic surfaces in the basin and erosion surfaces on the shoulders. It is constrained by an extensive database of boreholes and seismic reflection lines as well as published data.

Initial results in the Dannemarie Basin, which forms the SW limit of the URG, indicate that subsidence increased northward during the Rupelian, but southward during the Chattian. We propose that this change in asymmetry was due to the influence of the alpine flexure. During the Aquitanian the southern URG was uplifted along with its rift shoulders while subsidence continued in the northern part of the graben. Further to the south the alpine foreland basin continued to subside but no longer migrated northward. Therefore its forebulge also became stationary. We investigate the possibility that this forebulge was positioned on the southern URG.

At 12-11 Ma the alpine detachment encountered Triassic evaporitic facies and migrated rapidly toward the NW to form the Jura fold and thrust belt. The Jura fold belt overlaps the southern edge of the URG and the deformation front is classically identified to the south of Basel. However, the 3D model suggests that post-Pliocene alpine shortening propagated some 30 km further north in the graben, along the Triassic evaporitic decollement.

RCM3 : TUpm37 : F3
Rifting along Non-Volcanic Passive Margins: Evidence from the Mesozoic of the Alps and Western Iberia

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We examine aspects of the sedimentology and stratigraphy of rift basins that evolved in deep marine settings near the ocean-continent transition. We focus on the applicability of a low angle extensional detachment model developed in the Alps to the western Iberian margin, and on difficulties of objectively identifying syn-rift stratigraphic intervals in both areas. We present evidence obtained from ODP holes drilled in the Iberia Abyssal Plain. Despite the fact that all the holes were sited above highs in the acoustic basement and so did not penetrate a complete sedimentary tape recording of rifting, they do provide some constraints on the age and mechanism of rifting.

We suggest that published identifications of syn-rift intervals in distal basins off western Iberia and in the Southern and Eastern Alps have not demonstrated, using objective criteria, the occurrence of syn-rift stratigraphic intervals. They have, therefore, probably overestimated the duration of rifting by as much as 20 m.y. The absence of syn-rift related stratal divergence towards fault footwalls may be due to re-sedimentation of syn-rift sediments towards basin centres, no significant hangingwall rotation along flat detachment faults, or that the syn-rift interval is too thin to resolve on seismic data. The syn-rift episode beneath the deep Galicia margin postdates Tithonian-Berriasian shallow water carbonates, and predates Late Valanginian turbiditic sediments. Drilling results from the Iberia Abyssal Plain suggest a similar age because Tithonian siliciclastic mudrocks are overlain by Berriasian pelagic chalks. It seems likely that in both regions rifting lasted for less than 5 million years, probably from late Berriasian to early Valanginian.

At Site 1068 in the Iberia Abyssal Plain, the interpretation from seismic reflection data, of a low angle detachment dipping about 10º West, was confirmed by drilling which revealed sedimentary and tectonic breccias containing clasts of lower crustal rocks overlying a fault zone below which occurs serpentinised peridotite showing a downward decrease in deformation. At least 20.5 km of displacement is interpreted to have occurred along this fault, but it is not accompanied by large amplitude, rift related, topography. This paradox is resolved if the detachment developed as a deepening-downwards, rolling hinge, fault.

Tuesday PO Session

RCM3 : TUpo01 : PO
Modern Sands from Volcanic and Non-Volcanic Rifted Continental Margins: The Yemen Case (Red Sea and Gulf of Aden)

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The Gulf of Aden-Red Sea rift system represents a unique site to study geological evolution during the early stages of continental break-up, and a testing ground for various models of rift tectonics and sedimentation (Bosence 1998). The superbly exposed margins of southwestern Arabia in particular, which provide a 30 Ma-long record of magmatic activity preceding, accompanying and following the peak of tectonic extension (Davison et al. 1994; Menzies et al. 1997), represent an ideal natural laboratory for provenance studies, with the aim of defining an actualistic reference for both volcanic and non volcanic rifted-margin provenance. Due to arid climate and almost negligible intervention by man in this wild, largely untouched land, composition of modern sediments can be safely assumed as primary, and not affected by either chemical weathering or anthropic modifications. Along the young continental margins of Yemen, detritus is supplied in various proportions by rift-related magmatic rocks, and by sedimentary successions and underlying Pan-African basement exposed on the uplifted shoulders of the rift. Contrasting feldspatholithic volcano-plutonic ('volcanic rifted-margin provenance') and quartzolithic sedimentaclastic to arkosic basementaclastic signatures ('rift-shoulder provenance') are clearly differentiated on classic Dickinson's QFL diagrams (Dickinson 1985). Rift-related volcano-plutonic detrital suites (not previously recognized; e.g., Ingersoll, 1990) however plot within the 'magmatic arc' provenance field, and are not easily discriminated from sediment shed by Pacific-type magmatic arcs; diagnostic criteria include low P/F ratios due to supply from hypersolvus alkali-granite stocks, and bimodal (basalt/rhyolite) volcanic lithic populations. Rift-shoulder sands plot in the 'continental block' provenance field at increasing distance from the Q pole with increasing depth of erosion level ('undissected' to 'dissected' stages). Sand from undissected rift-shoulders entirely consists of recycled quartz and carbonate grains from pre-rift sedimentary successions; arkosic sand from Precambrian basement rocks, showing remarkably consistent composition from the Red Sea to the Gulf of Aden, invariably includes significant amounts of excess quartz with respect to 'ideal arkose'. 'Volcanic rifted-margin' and 'rift-shoulder' provenances are also characterized by markedly contrasting dense-mineral assemblages. Volcaniclastic Red Sea sands contain mostly brown augite from the Yemen Traps, associated with orthopyroxenes (chiefly hypersthene) from deeper-seated gabbroic rocks; alkali-basalt fields of the Gulf of Aden also shed common olivine and locally spinel and enstatite. Rift-shoulder detritus is instead dominated by metamorphic minerals. Amphibolite-facies gneiss terranes mostly supply hornblende, associated with either tremolite-actinolite and epidote (e.g., sand from the Asir terrane) or garnet (e.g., sand from the Abas terrane); greenschist-facies arc terranes mostly shed epidote (e.g., Mukalla terrane). Comparable mineralogical suites characterize the Nile sands (Shukri, 1949), fed from the western shoulder of the Red Sea rift and Ethiopian volcanic plateau. Diagnostic signatures and compositional trends recorded by modern Yemen sands can help interpreting provenance of ancient rift-related sandstone suites.

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RCM3 : TUpo02 : PO
Rifting and Crustal Structure across the Western Tyrrhenian Basin: New Seismic Images

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The Neogene Tyrrhenian Basin is considered a natural laboratory where to interpret in detail the achitecture and the tectonic evolution of young rifted margins and the emplacement of oceanic crust. New geological and geophysical studies have been performed and the interpretation of about 2000km of multichannel seismic lines furthermore improved the structural knowledges of the Tyrrhenian continental margins. The seismic data, previously achieved by several European Academic Institutions in the two last decades, were recently reprocessed at IGM-CNR Bologna in the frame of a 40% MURST Italian Project (1998-2000). The analysed seismic profiles are mainly located on the whole Sardinian Continental Margin, and the longest one crosses, from W to E, the whole Tyrrhenian Basin reaching the Campanian Continental Margin. The interpretation has been calibrated using, whenever possible, the DSDP and ODP Sites results and other sampling data. In addition refraction, heat-flow and aeromagnetic data, available along the seismic profiles, have been taken into account. In the Sardinian Continental Margin a major tectonic lineament, running near latitude 40º N roughly along the present Orosei Canyon, separates two crustal sectors with different structural evolution, subsidence and extensional rates. South of this tectonic lineament, several pre-evaporitic seismic sequences are observed and a complex late Oligocene to intra-Tortonian structural evolution is defined. Across the whole Cornaglia Terrace as far East as the Selli Fault exensional listric faults generate syn-rift wedges of intra-Tortonian to intra-Messinian age. The sector spanning from the Selli Fault to the Vavilov Plain, appears as a complex, strongly thinned area in which extensional listric faults of intra-Messinian to intra-Pliocene age interplay with Pliocene volcanic and subvolcanic bodies. The stratigraphic and structural observations suggest that the structural architecture of the Sardinian Margin is characterized by half grabens and continental fault-blocks tilted both to the W and to the E which sole out on a crustal discontinuity, imaged by regional sub-horizontal reflectors located at 7 sec. TWT (about 10 km deep). The continent ocean boundary (COB) at the end of the Sardinian Margin is wide with a complex transitions zone. The Vavilov Bathyal Plain shows, beneath a blanket of Pliocene-Quaternary sediments, a rough topography closely recalling top of oceanic layer 2. In some sectors, however, enigmatic reflectors occur inside the oceanic crust which is only 6-7 km thick. They may represent volcanoclastic sequences interfingering with submarine lava-flows (recorded at ODP Sites 655 and 651) or structural deformations tied to the tectonic uplift of rocks of the LID, as observed at ODP Site 651. In the Campanian Margin the COB is really sharp and subvertical, since oceanic layer 2 passing abruptly to the Flavio Gioia Smt., made by continental units, and not or poorly rotated during extension.

RCM3 : TUpo03 : PO
A Synthesis of the Quaternary Sedimentary Architecture of the Iberian Spanish Continental Margins (Mediterranean and Gulf of Cadiz)

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In this contribution we examine the Quaternary sedimentary architecture of the Iberian Spanish continental margins, in the Mediterranean Sea and Gulf of Cadiz, in order to synthesise the geometry, strata pattern and preservation of sedimentary systems in the shelf, slope, base-of-slope and basin floor. In a general way, the shelf architecture is mainly defined by topsets and seaward dipping, inclined deposits, locally intercalated with coastal onlaping deposits; this architecture is integrated by shelf delta, prodelta and transgressive sedimentary systems. The slope and base-of-slope architecture is defined by prograding, divergent and parallel deposits that merge updip with the shelf deposits; they mainly represent regressive sedimentary systems. This type of architecture complicates in those channelised areas where turbidite systems and instability deposits develop. In these cases, the architecture is defined by laterally discontinuous and chaotic deposits, lenticular packages, and numerous valley (canyons and channels) incisions, that represent canyon-fill deposits, channel-fill deposits, overbank deposits, and mass-flow deposits. The basin architecture is mainly defined by parallel and onlaping stratified deposits that represent the downslope continuation of the base-of-slope deposits.

Most of the Quaternary studies on the Iberian continental margins indicate that facies architecture has developed mainly in response to sea-level fluctuations (Alonso et al., 1990; Farrán et al., 1990; Ercilla et al., 1994; Ercilla et al., 1995; Choicci et al., 1997). Nevertheless, local factors seem to play an important role in the sedimentary architecture, specifically in the strata pattern and its preservation, and sedimentary distribution. So, tectonism was responsible of: preservation of regressive deposits on the shelf; strong lateral variations in the growth pattern of the shelf and slope; and lateral sedimentary continuity affected by faults, diapirs, volcanoes, in the slope, base-of-slope and basin. Physiography conditioned the across-margin location of sedimentary depocenters, and the geometry (shape and dimensions) and sedimentary distribution of unchannelised slope deposits and turbidite deposits from slope to basin. Sediment supply conditioned along-margin location of sedimentary depocenters, development of prodelta, and predominant direction of progradation on the shelf; across-margin location of sedimentary depocenters on the base-of-slope and basin; and thickness of sedimentary systems from shelf to basin. Finally, oceanography conditioned the direction of progradation on the shelf; and geometry and strata pattern in the slope and base-of-slope.

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RCM3 : TUpo04 : PO
Seismic Modelling of Detachment Systems in Magma-Poor Rifted Margins

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Synthetic seismic sections of exposed fragments of magma-poor rifted margins provide new insights into the potential of seismic methods to image rift-related detachment systems. Remnants of the former Tethyan magma-poor rifted margins are preserved in the Tasna and Platta-Err nappes of eastern Switzerland. Exceptional seismic-scale outcrops provide detailed insights into the geometries and kinematic evolution of rift-related detachment systems. These outcrops show only little overprint by Alpine deformation and they close the observational gap between deep-sea drilling cores and seismic reflection data along present-day magma-poor rifted margins. We investigate the seismic velocity structure of pertinent examples of detachment systems at shallow levels within the basement, such as detachment faults that (i) truncate tilted blocks in more proximal areas of the margin, that (ii) separate lower continental crust from upper mantle in a more distal setting, and that (iii) exhume upper mantle on the sea floor at the ocean-continent transition. Modelling a realistic seismic response applying a finite-differences solution to the acoustic wave equation including multiples, diffractions, wave scattering, and spherical attenuation suggests that low-angle detachment systems at shallow basement levels are difficult to image. These features have a relatively week seismic response compared with the response from the sedimentary cover. However, the detachment systems can be indirectly identified by differences in seismic facies. Because seismic facies is a result of small-scale velocity heterogeneity, simplified layered velocity models based only on uniform velocities are not adequate. We describe the seismic velocity field as V(x,z) = V0(x,z) + dV(x,z), where V0 is the deterministic large-scale velocity distribution and dV are small-scale velocity fluctuations. With this more generic velocity model, effects such as reflection scattering that influence seismic facies can be modelled. This in turn allows for a better interpretation of seismic reflection data from present-day margins.

RCM3 : TUpo05 : PO
Field Evidences for a Brittle Detachment Fault Controlling the Evolution of the Dissymetric Corinth-Patras Rift (Greece)

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The Gulf of Corinth is an E-W trending asymmetric rift located between continental Greece and Peloponnese. Beneath the western gulf, microseismicity and large earthquakes focal mechanisms evidence a shallow, low angle N-dipping detachment fault. In northern Peloponnese, we present structural, sedimentological and geomorphological observations showing that this detachment crops out 12 to 32 km south of the coast of the gulf. It can be mapped over 70 km long between the southern side of Panakaikon mountain in the west and Nemea in the east. In the area of Khelmos and Ziria mountains, this low-angle fault offsets by 4 to 6 km the alpine nappe pile. Due to its listric profile near the surface, a large rollover formed in its hanging wall, affecting the downthrown nappe pile and the first conglomeratic synrift deposits. Uplift and southward tilting of the footwall flattened the southern part of the detachment, which became inactive. More northerly located normal faults formed, linking the northern, still active detachment, to the surface. Thus the rift depocenter moved north of these new faults. The dip difference between these faults and the detachment caused the formation of new rollover structures. This general evolution scheme of the rift during about 1 Myr resulted in the progressive emersion, uplift and southward tilting of northern Peloponnesus; the presently active normal faults are located along the southern coast of the gulf. Further works will concern the shape of the detachment fault and its implications on the geometrical and chronological N-S evolution of the normal fault systems. In parallel U/Th dating of syntectonic calcite and stratigraphical analyses of the synrift deposits will inform us about the lateral propagation of the fault activity and thus to reach a spatio-temporal evolution of the rift.

RCM3 : TUpo06 : PO
Post-Collisional Potassic Magmatism on the Tibetan Plateau: Temporal and Spatial Evolution

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The collision of India with Asia since early Cenozoic time resulted in the Tibetan plateau and surrounding mountain ranges. Despite numerous investigations in the region, the geodynamic processes that accounted for the formation and evolution of the plateau remain highly controversial. To better understand these processes, we present new chronological and geochemical data of post-collisional magmas from eastern Tibet. The magmas range from mafic to felsic compositions. They are potassic, enriched in the large ion lithophile and light rare earth elements, and depleted in Nb, Ta and Ti, suggesting a metasomatized continental lithospheric mantle origin. Combining with published information from the western part of the plateau, three episodes of post-collisional potassic magmatism characterized by similar geochemical features can be identified in different localities. These are: (1) 40-30 Ma group from the eastern Qiangtang terrane, eastern Tibet, (2) 25-16 Ma group from the Lhasa terrane, southern Tibet, and (3) <15 Ma group from the western Qiangtang and Songpan-Ganze terranes, northern Tibet. Each group, moreover, marks with distinctive trace elemental and isotopic signatures. This temporal and spatial variation indicates a heterogeneous nature of the Tibetan lithospheric mantle, which we infer to have resulted from enrichment events that occurred prior to the terrane accretion. Such heterogeneity implies that variation in the compositional, and/or thermal, structure of the Tibetan lithosphere could have placed an important control on the timing and places of the magmatism, and supports the notion that diachronous removal of thickened lithosphere took place in the Tibetan plateau.

RCM3 : TUpo07 : PO
Interdisciplinary Study of the Lithospheric Structure across The Møre Continental Margin (Northern North-Atlantic)

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This poster presents the 2D lithospheric structure of the Møre continental margin, south of the Jan Mayen lineament that has been rifted since late Palaeozoic-early Mesozoic times. Being part of the North Atlantic Igneous Province, its actual configuration is characterised by an important crustal thinning episode (mainly inherited from the Mesozoic extension), underplating below the continental crust and an anomalously thick oceanic crust, caused by the large magmatic activity that took place during the Tertiary. The present-day lithospheric structure of the area has been studied along a transect that crosses the margin from the Norwegian mainland to approximately magnetic anomaly 24A-24B. Forward modelling has been performed to fit observed elevation, gravity, geoid and heat flow data assuming local isostasy and steady state. Available seismic reflection profiles have been used to determine the geometry of the sedimentary cover. The structure of the crust has been constrained using information from previously published deep seismic data. The results indicate that the lithosphere thickens from c. 50 km beneath the oceanic domain to c. 150 km under the Scandinavian Peninsula. The geometry of the calculated model also shows that the anomalous oceanic crust reaches a thickness of about 11.5 km. The magmatic underplating, up to 6 km thick, extends from the Ocean-Continent boundary towards the continental domain for c. 200 km, mainly coinciding with the zone where continental crust is thinner. A lower crust, with a high P-wave velocity and density, extending from under the Møre basin to the East, towards Norway, has also been characterised.

RCM3 : TUpo08 : PO
Rifts on Continental Basalt Fields Accord to Taphrogenesis in Geocycles

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Tectonically 'passive margins' of are the parts of larger basalt fields. The fields rose after the erosion and descent of adjacent orogens. Other parts of fields with the degraded orogens are dived in ocean. This is confirmed by under-lava layers. The crash of fold zones beneth to after G.Shtille is taphrogenesis. The author (Makarenko,1983) has descovered novel circcumstances of cover basalt, which correspond to biocrises on the marks of geoperiods (Makarenko,1997). The tectonotype of basalt fields: the Urals and TransUrals.

The cover lavas in the space of tectonic forms correspond to the rears of thrust-fold zones. Lavas are poured out with sinking. At the fronts of such zones there are orogenic deeps with debris on stable frame. (Here it may be a recurrent-orogenic zone, or an island cordilleras of a future thrust-fold zone). The time of volcanites accumulation roughly is up to 1 mm/yr. The riftogenesis is always more late (on the average on 30 mm/yr.). On the continents it corresponds to uprising of basalt provinces. Residual (taphrogenic) are the grabens only. Diversified basites of rifts are exposed insignificantly. Circumstances for: Hercinides - folds, orogenesis, final basalts, taphrogenesis (Urals - TransUrals); Late Hercinides; Cymmerides; Late Cymmerides and for Alpides - Laramides. This correspondingly: P/T, T, T/J, J/K (Capides - Karroo); T/J, J, J/K, K/Pg (AntarctAndes - Bishop); J/K, K, K/Pg, Pg/N (Verchojanydes); K/Pg, Pg, Pg/N, N/Q (Cordilleras-Plato Columbia). In modern orogens of Late Alpides (Hymalaians et al.): folds g/N, orogenesis N/Q. Those zones have reached the epoch of basalts. Mobilism ignores this position.

The age of ocean basalts, rifts (DSDP) made possible the reconstruction of global system of fold zones. This system is symmetrical with regard to the Earth's axis of rotation. This basic fenomena is unsuperable (maps).

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RCM3 : TUpo09 : PO
Gabbroic Rocks from a Fossil Continent-Ocean Transition: The Example of the External Liguride Ophiolites (Northern Apennines, Italy)

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The External Liguride Units of the Northern Apennines display thick sedimentary melanges of Upper Cretaceous age where with large slide blocks of Jurassic ophiolites are associated with continental lithologies, mainly peraluminous granitoids and granulite-facies rocks. The ophiolites are mostly composed of mantle ultramafics and MOR-basalts. They have been considered as representative of the transitional realm between the Adria continental crust and the Ligurian Tethys oceanic crust (Marroni et al., 1998). Gabbroic rocks are rare and occur as (i) decametric to hectometric slide-blocks, (ii) small lenticular bodies intruding lherzolitic mantle rocks of subcontinental origin. The slide blocks are locally covered by radiolarian cherts, testifying exhumation to ocean-floor. Gabbroic rocks intruding the mantle peridotites postdate the re-equilibration to plagioclase-facies conditions, which has been dated at about 164 Ma (Rampone et al., 1995). The gabbroic rocks consist of: (i) medium to coarse-grained troctolites and olivine-bearing gabbros; (ii) medium-grained Fe-Ti oxide-bearing gabbros, locally showing patches of porphyritic microgabbro with clinopyroxene and plagioclase phenocrysts, and apatite-rich Fe-diorites. Rodingitic assemblages consisting of prehnite + vesuvianite + grossular + epidote + chlorite occur along the margins of the gabbroic lenses enclosed into the mantle rocks. The gabbroic slide blocks are crosscut by discordant bodies of Fe-Ti oxide-bearing microgabbro and undeformed doleritic dykes with T-MORB affinity. The latter are similar to the widespread basaltic rocks of the External Liguride Units (Marroni et al., 1998). Whole-rock compositions evidence large variations in MgO/(FeO+MgO), ranging beween 0.89 and 0.26; decreasing values of MgO/(FeO+MgO) are accompanied by increasing TiO_2, V, Zr, Y and decreasing Ni and Cr contents. As a whole, petrographic features, mineral and whole-rock compositions are comparable to those observed for the MOR-type gabbroic rocks of the Internal Liguride ophiolites, i.e. the intra-oceanic domain of the Ligurian Tethys (Tribuzio et al., in press). The gabbroic rocks are frequently characterized by the development of millimetric to metric high-temperature shear zones with development of protomylonitic to mylonitic and ultramylonitic textures. Ductile deformation is accompanied by sin-kinematic crystallization of neoblastic clinopyroxene + plagioclase ±titanian pargasite ±ilmenite ±spinel. Both deformed and undeformed rocks display widespread subgreenschist metamorphic assemblages (prehnite + epidote + chlorite + tremolite/actinolite + sphene), locally grown along veins and intragranular fractures. The gabbroic rocks from the Internal Liguride ophiolites differ in the widespread development of lower amphibolite- to greenschist-facies assemblages, which were likely related to the development of an active high-temperature hydrothermal system (Tribuzio et al., 1995; 1997). The gabbroic rocks from the External Liguride ophiolites testify the injection of MOR-type magmas in subcontinental peridotites during their exhumation in a passive rifting context, similarly to what is observed for the gabbros of the present-day West Iberian OCT (e.g. Cornen et al., 1999).

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Wednesday AM Session

RCM3 : WEam02 : F3

Architecture and Tectonic Evolution of Magma-Poor Margins: Present-Day Iberian and Ancient Tethyan Margins

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A comparison of ancient margins of the Tethys ocean in the Tasna and Platta-Err nappes (SW Switzerland) with the present-day Iberian margins shows that although the margins are of different age and ultimately had a different fate, their architectures and tectonic evolutions are very similar. Rifting initiated in proximal parts of the future margins and was characterised by listric faults soling out at mid-crustal levels decoupling deformation in the upper mantle from deformation in the upper crust. Extension was distributed over the entire margin and lasted some tens of millions years. Magmatism was essentially absent at this stage, and the margin architecture was, on a margin scale, symmetric.

During an advanced stage of rifting, when the crust was locally already thinned to about 10 km, rifting shifted towards the area of the future ocean-continent transition (OCT). The shift of extension and its localisation within the OCT were associated with a change in the mode of extension from downward-flattening listric to upward-flattening anti-listric faults. These latter faults can explain three characteristic features observed within the OCT: (1) large fault offsets resulting in a minor submarine relief; (2) exhumation of subcontinental mantle by pulling it out from underneath a relatively stable hanging wall; and (3) the formation of tectono-sedimentary breccias by a conveyor belt type sediment accumulation whereby the exhumed footwall rocks were fractured, exposed, and redeposited along the same active fault system.

In the Tethyan margins, field relations show that exhumation of subcontinental mantle at the seafloor was partly contemporaneous with the first emplacement of syn-kinematic gabbro intrusions, immediately followed by the emplacement of massive MOR pillow basalts reflecting the onset of seafloor spreading. Thus, the first voluminous basalts showing an unequivocal oceanic signature overlie tectonically exhumed subcontinental mantle.

Along both the Iberian and Tethyan margins the transition from amagmatic symmetric rifting to steady-state seafloor spreading includes a transient phase of simple-shear dominated, asymmetric rifting. This phase is characterised by the localisation of extension, the occurrence of top-to-the-ocean upward-flattening faults leading to the exhumation of subcontinental mantle lithosphere forming the OCT, and the rise of the asthenospheric mantle. We suggest, that after a first phase of passive rifting, largely controlled by the pre-rift thermal state of the lithosphere and pre-existing weaknesses, lithospheric thinning created a diapiric buoyancy instability of the mantle asthenosphere. Asthenospheric uplift gave rise to transient simple-shear extension, resulting in weakening of the lithosphere and triggering melt production which resulted in the final break-up of the lithospheric mantle and the onset of seafloor spreading.

RCM3 : WEam03 : F3

MORB-Type Magmatism: End of Passive Rifting and Initiation of a Slow Spreading System. The Platta Ocean-Continent Transition, Graubünden, Eastern Switzerland

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Exhumation of subcontinental mantle rocks and their exposure at the sea floor is documented along several non-volcanic passive continental margins where it occurred during break-up of the continental lithosphere. However, the transition from passive rifting to a sea-floor spreading is still poorly documented. Here, we present field, tectonic, petrological and geochemical datas from a segment of the former Liguro-Piemontese ocean-continent transition (Platta nappe, Eastern Switzerland) which offers the opportunity to study the transition from passive rifting and detachment faulting to the formation of a slow spreading system.

The south Penninic Platta nappe consists of two massive serpentinite bodies which locally preserves primary contacts to continental derived breccias, gabbros and pillow basalts, and post-rift sediments. Palinspastic reconstruction of this OCT shows that continent-derived extensional allochthons overlie both serpentinite bodies and that the volume of magmatic rocks increases oceanwards. Chemical composition of clinopyroxenes reveals that the serpentinite close to the continent may represent spinel peridotite mixed with (garnet)-pyroxenite layers while the more distal serpentinite is a pyroxenite-free peridotite that equilibrated in the plagioclase stability field.

Gabbros intruded into these previously serpentinized subcontinental mantle rocks; they range from olivine-bearing Mg-gabbro, to highly differentiated Fe-Ti-P-gabbro, diorite and albitite. Trace-element chemistry shows that these gabbros represent either frozen liquids or products of in-situ crystallization of such liquids at shallow depths. The latter process led to progressive enrichment in REE and incompatible elements such as Ti, P, Th and U and finally to the crystallisation of apatite and zircons in the more differentiated gabbros. U-Pb dating of zircons from 4 different gabbros yielded precise ages of 161 ±1 Ma. Initial Hf isotope data of zircons and Nd isotope data of gabbros indicate a N-MORB type mantle source of the melt.

The pillow lavas, which stratigraphically overlie the exhumed mantle rocks, grade from T-MORB to N-MORB oceanward. They represent aggregated melts from moderate degrees of partial melting of an asthenospheric source as testified by trace element chemistry and isotope data. Furthermore, they share similar trace element composition and εNd values with the parental liquids of the gabbros indicating that gabbros and basalt originated from similar melts and differ only by their level of crystallisation.

The emplacement of these MORB-type magmatic rocks mark the end of the rifting phase and document the onset of a sea-floor spreading system across an exhumed subcontinental mantle.

RCM3 : WEam04 : F3
Plagioclase Peridotite along Continental Margins: Controlled by Subsolidus Equilibration or Melt/Rock Reaction?

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Extensive geologic and petrologic evidence from both on-land and off-shore studies indicates that major masses of ultramafic rocks exposed along continent-ocean transitions are former subcontinental mantle. Most of them are variably depleted spinel peridotites, but plagioclase peridotites are also found. One hypothesis is that plagioclase peridotites record a subsolidus history during emplacement. Another hypothesis is that they represent impregnated rocks formed by percolation of basaltic liquid and melt/rock reaction. The genesis of plagioclase peridotites exposed along passive continental margins is thus crucial to constrain the thermal evolution of the margin during rifting and the onset of sea-floor spreading. A LA-ICP-MS trace element study was undertaken to explore the chemical variations of mantle clinopyroxene along a former continent-ocean transition in the Alps (Platta nappe) where the geometry of the passive margin is well constrained[1]. The chemical composition of clinopyroxenes reveals that the ultramafic rocks close to the continent (upper serpentinite) may represent spinel peridotite mixed with (garnet)-pyroxenite layers while the ultramafic rocks at some distance from the continent (lower serpentinite) are pyroxenite-free peridotite that equilibrated in the plagioclase stability field. Bulk rock analyses of lower serpentinites show fertile to extremly depleted compositions. Clinopyroxene of the latter shows an extreme LREE depletion $(Ce/Yb)_n < 0.01$ and represents the residue of near-fractional melting (<10%) of peridotite, similar to what is found in abyssal peridotites[2]. However, highly depleted and fertile clinopyroxene can be found within the same outcrop. Most of the fertile clinopyroxene shows a lower content in Al, Na, Sr, and a higher content in Y, Sc, V, Zr, Cr, Ti, $(Gd/Yb)_n$ relative to clinopyroxene from spinel peridotites. Some incompatible elements, e.g. Sr and Zr, are negatively correlated, similar to results from the Ligurian Alps[3]. Clinopyroxene from the lower serpentinite has a convex-upward REE pattern, a negative Eu and Sr anomaly and $(Gd/Yb)_n > 1$ which we ascribe to equilibration with plagioclase and orthopyroxene. However, an evaluation of existing trace element data of plagioclase peridotites indicates that the trace element signatures do not clearly distinguish between subsolidus equilibration or impregnation and melt-rock reaction. Textural relationships indicate that some plagioclase peridotites in the Platta nappe were probably formed by melt infiltration and melt-rock reaction. Currently we are investigating the isotopic composition of clinopyroxene to test the hypotheses whether plagioclase peridotites are related to the onset of magmatism and sea-floor spreading or if they represent and older and independent event in the lithospheric mantle.

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RCM3 : WEam05 : F3
Petrography of Volcaniclastic and Ophiolitic Clasts in the Western Woodlark Basin

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The Western Woodlark Basin represents the evolution from continental breakup to seafloor spreading in the region of Papua New Guinea since Late Miocene to Recent time, as a back-arc basin related to subduction (Leg 180 Shipboard Scientific Party, 1999). A nearly N-S transect of 11 sites was drilled: 3 Sites on the down-flexed northern margin, 5 Sites into the rift basin sediments above the low-angle normal fault zone, and 3 Sites on the footwall fault block, Moresby Seamount. Here, a continental metamorphic crust made by gneisses and amphibolites with minor granites and a Cretaceous-Eocene oceanic crust likely obducted (Robertson et al., in press) were recovered below the fault zone. Clasts investigated from sedimentary sequences (Middle Miocene to Pleistocene) were grouped as follows: a) continental crust rocks: i) granites ii) quartzschists, micaschists, gneisses and amphibolites b) ocean-floor rocks: iii) serpentinites iv) Fe-Ti oxide gabbros to quartz-diorites v) dolerites and basalts c) fault rocks (metamorphic sole?): vi) talcschists, serpentineschists, Chl-Am schists, epidosites d) island-arc-volcanic rocks: vii) calc-alkaline volcanic products. Groups i) and ii) are localized in the footwall and in the rift basin sites; they represent the progressive unroofing of the basement along the low-angle normal fault. Groups iii), iv), and v) represent an ocean-floor sequence including serpentinized ultrafemic rocks, evolved gabbros (layer 3A), dolerites (layer 2A) and basalts (layer 2B). Clasts of all layers have different stratigraphic distribution consistent with progressive erosion at deeper levels. The deepest clasts of the effusive sequence show apparent alteration, as a probable effect of reworking in the conglomerates. Gabbro clasts appear in the footwall and in the northern margin, while serpentinites are diffuse in the footwall and rift basin. Evidence of low-grade metamorphism (prehnite in gabbros and dolerites; pumpellyite in dolerites at Site 1116) suggests an overprint during Early to Middle Miocene subduction (Robertson et al., in press). In the northern margin dolerites are overwhelming and localized in the basal conglomerate. Widespread spilitization, low-grade alteration prevent analysis of samples, however the composition from Ol-phyric to Fe-basalts suggests tholeiitic seriality. The composition of volcanic products ranges from basalt to dacite; phenocrysts include plagioclase, clinopyroxene, rare orthopyroxene, K-feldspar and quartz, red-green hornblende, and biotite. Modes and crystallization order correlate with the degree of evolution of the rock and with the composition of associated glass, but also suggest variations from medium -K to high -K calc-alkaline seriality. Lava clasts, sometimes coarse, occur mostly in the rift basin and footwall. Small vitrophyric fragments are diffuse; in the northern margin only single-grain phenoclasts occur concentrated as pockets and seams, suggesting a fallout origin, and frequently associated with pumices (transport by floatation).

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RCM3 : WEam06 : F3
The Neoproterozoic Volcanic Rifted Margin of Baltica as Preserved by Thrust Sheets of the Scandinavian Caledonides

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Thrust sheets of the Scandinavian Caledonides preserve fragments of the volcanic rifted Baltoscandian Margin (BM), which formed during late breakup of Rodinia and accreted to Baltica during Early Palaeozoic closure of the Gir Sea (Torsvik & Rehnström, in press) and the Iapetus Ocean. The latter ocean closed by subduction of the BM beneath Greenland in Late Silurian to Mid-Devonian time i. e. some 300 Ma before the onset of spreading in Mid-Cretaceous and the formation of the Tertiary Volcanic Rifted Margin of East Greenland.

Fragments of the BM include extensive (<1000 km long) mafic dyke swarms of the Baltoscandian rift basins; sheeted dyke complexes emplaced in sandstones and evaporites, and dyke-intruded pillow lavas hosted in marble, black schist and quartzite of inferred outermost margin derivation. One dyke swarm occurs in the autochthonous Sveconorwegian-Grenvillian basement at Egersund. Fragments of the oceanic crust include dolerite-intruded gabbro with dykes of plagiogranite and rare peridotite fragments (Kebnekaise Mts.) and spilitized basaltic lavas and Cu-Fe sulphide mineralizations (Mt. Sylarna). The superbly exposed Seiland Igneous Province (SIP) may represent a section of the lower crust/mantle boundary of the rifted margin of Baltica, bounded by granulite facies shear zones and dominated by gabbroic and ultramafic rocks. The province also includes alkaline rocks and dykes carrying xenoliths from the lithospheric mantle. Fragments of the subcontinental mantle were tectonically emplaced during subduction and imbrication of the BM and now occur as numerous intercalated solitary ultramafite bodies within eclogite-bearing thrust sheets.

Dolerite dykes of the Baltoscandian rift basins cut Varangerian tillites. Thus, if the 610-590 Ma age range for the Varanger glaciation (Knoll & Walter, 1992) is preferred, these dykes are younger than 610 Ma. Similar ages were obtained for the Egersund dykes (616±3 MA; Bingen et al., 1997) and the sheeted dyke complex of the Sarek Mts. (608±1 Ma; Svenningsen, 1999). The corresponding rift-magmatic evolution of the SIP lasted from c. 600 to c. 550 Ma (Reginiussen et al., 1995).

Alkaline and most subalkaline dykes of the BM dyke swarms are enriched in incompatible trace elements and REE relative to E-MORB and plot between MORB and enriched mantle on isotopic ratio graphs. Alkaline dykes of the SIP have ocean island basalt affinity (Reginiussen et al., 1995). The segment of a volcanic rifted margin preserved in the Scandinavian Caledonides most probably belonged to a much larger igneous province. This is also implied by broadly coeval magmatism along the Laurentian arms of Rodinia breakup, and along the southeast, Vendian (650-570 Ma) margin of Baltica. In the latter area, bimodal volcanism in aulacogens was voluminous (e. g. the 770 km long Volyn flood basalt). Questions whether the BM rift magmatism has a plume signature and is a fragment of a Large Igneous Province will be addressed.

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RCM3 : WEam07 : F3
A Vendian Paleolatitude for Baltica – Paleomagnetic Constraints from the Sarek Dyke Swarm, Northern Swedish Caledonides

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The Vendian (650-544 Ma) was a period of geological unrest, with the break-up of the supercontinent Rodinia and widespread glaciations. Evidence of these events abounds in the Scandinavian Caledonides, but a lack of reliable absolute age dates, paleomagnetic data as well as the complex deformation during Caledonian orogenesis hampers the interpretation of the Vendian record. In the Sarek National Park in northern Sweden (67°N), a dense mafic dyke swarm - Sarek Dyke Swarm (SDS) - is connected with the Vendian rifting (608 ±1 Ma; U-Pb on zircons in mafic pegmatites). The SDS occurs in a thrust sheet, which was thrust c. 600 km to the east-southeast during the collision between continents Baltica and Laurentia in the Silurian. Still, in the interior of the thrust sheet, rocks show little or no evidence of Caledonian penetrative structural or metamorphic overprinting. Roughly 70-80% of the volume of the nappe consists of mafic dykes intruded into a 4-5 km thick sedimentary sequence, originating in a continent-ocean transition zone. The dykes consist of diabase with well preserved magmatic texture and mineralogy, and also carry primary magmatic natural remanent magnetizations (NRM). The NRM yield well-defined poles, but the dykes have been detached, tilted and transported over long distances. The original strike of the dykes can not be obtained, but restoring them to the paleo-horizontal is possible. After this correction for Caledonian tilting of the entire sequence, a paleolatitude of c. 8° (N or S) is indicated for the rifted margin of Baltica at 608 Ma, i.e. near the Equator. The paleopoles from the dykes form three distinct groups; one that can be related to Silurian/Caledonian overprint, and two groups that are clearly connected with the emplacement and primary crystallization of the dykes. This indicates block rotations of the dyke complex in close connection with the formation of the passive margin. However, these rotations occurred around axes nearly parallel to the strike of the dykes. Meta-evaporites, meta-sandstones and quartzites, with a subordinate, but conspicuous, thin metamict conglomerate horizon dominate the hosting sequence of sedimentary rocks. The conglomerate occurs at a stratigraphic level corresponding to that of glacial deposits in similar Vendian sequences in other parts of the Baltoscandian margin. The sediments in Sarek were deposited and deformed in close connection to dyke emplacement; deposition was penecontemporaneous with deformation, which in turn affected the earliest generations of dykes.

RCM3 : WEam11 : F3
A Combined Plume-Influenced and Slab-Pull-Related Model for Late Triassic Continental Break-Up in the Eastern Mediterranean Region

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ODP and marine geophysical studies indicate a two-fold division of present-day orthogonally rifted passive continental margins into 'Volcanic', or plume-related (e.g. E Greenland) and 'Non-volcanic' (e.g. Iberia). However, it is not yet known how typical these margin types are of ancient rifts/passive margins now emplaced within orogens (e.g. Iapetus). The deep structure of present-day margins has to be inferred from geophysics, but may be deduced from well exposed tectonically emplaced examples (e.g. Oman). Here, we focus on rifting of Neotethys in the E. Mediterranean region. Disagreements exist over the timing of continental break-up: Late Permian, Mid-Late Triassic and mid Cretaceous ages have all been proposed for initial sea-floor spreading. However, well exposed field relations in Greece (e.g. Pindos-Olonos zone) and Turkey (e.g. Antalya region) document a history of Late Permian rifting, then extensive Triassic rift-related volcanism that peaked in Carnian-Norian time (in Antalya), followed by the establishment of subsiding passive margins. Triassic tholeiites in Antalya, associated with deep-sea radiolarian sediments, range from within-plate basalt, to transitional basalt and mid-ocean ridge basalt, and are interpreted as recording continental break-up. The widespread Triassic rift basalts exhibit consistently positive delta-Nb trace-element signatures consistent with the involvement of a contemporaneous mantle plume influence. In some areas (S Greece), broadly coeval supra-subduction zone-type basalts apparently were extracted from previously modified lithosphere. However, compared to the north Atlantic margins magmatism is modest in scale and regional thermal uplift is unknown. On the other hand, no evidence is present in the E Mediterranean rifts of pervasive extensional exhumation, or peridotite protrusions as in Iberian-type non-volcanic rifts. The Mediterranean Triassic rifts, thus, appear to be intermediate between the two known rift margin types and may represent activity of a number of small plumes beneath Gondwana. In addition, there is now strong evidence that northward subduction of Tethyan ocean crust took place in Late Triassic time beneath the S margin of Eurasia (e.g. central Pontides). Consequently, sea-floor spreading in the southern Neotethys region may have been triggered in the Late Triassic by the combined effects of slab-pull related to northward subduction beneath Eurasia, and small-plume-induced crustal weakening of Gondwana further south.

RCM3 : WEam12 : F3
Stratigraphy and Geochemistry of Cretaceous Volcano-Sedimentary Units in the North of Istanbul: Development of a Volcanic Rifted Margin, Western Pontides, Turkey

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A volcano-sedimentary sequence of Cretaceous age, termed the Kavaklar group, is exposed to the north of Istanbul, on the banks of northern Bosphorous and along southern cost of the Black Sea. It is made up of volcaniclastic beds intercalated with minor lava flows and silisiclastic turbidites. Dykes and sills of intermediate to basic composition cut this sequence. A Palaeozoic sequence (i.e. the Palaeozoic of Istanbul) thrust over this unit from the south. Nowhere to the south of this major trust line the Kavaklar group is exposed.

The Kavaklar group forms a NW-dipping sequence with a thickness of over 1 km. A flysch unit containing occasional intercalations of volcaniclastic boulderstones and lavas is exposed at the base. Soft sediment deformation structures are abundant in this part of the unit. A thick pile of coarse-grained volcaniclastic sediments consisting of volcaniclastic boulderstones, volcanic breccias, hyaloclastites and sandstones conformably overlies this flysch. Individual clasts range in size from a millimetre to a few metres, while thickness of the individual beds ranges from a few meters to ca. 40 m. They span a compositional range from basaltic andesite to rhyolite. On the basis of their mineral content and texture, both lavas and clasts may be divided into three types: (1) aphyric, (2) plagioclase + pyroxene-phyric, (3) plagioclase + amphibole-phyric lavas. Both thickness of individual beds and grain sizes gradually decrease towards the top of the succession. This uppermost part of the sequence consists of sandstones with rare boulderstone intercalations.

There has been a consensus among researchers that this sequence corresponds to a continental margin arc, based on petrographic data. Our geochemical data, however, indicate that the melts appear to have derived from an enriched source with presence of a subduction component. Moreover, the stratigraphy is not compatible with the arc setting as lavas are volumetrically scarce in the succession. We argue that the Kavaklar Group represents an extensional volcanism, related to the opening of the Black Sea by rifting during the Mid- to Late Cretaceous period. Initial crustal extension appears to have resulted in an irregular topography with structural lows and highs. The structural lows were filled by terrigenous turbidites with occassional lava flows and volcaniclastic interbeds. This was followed by build up of a marginal volcanic belt. Mass wasting of the volcanic province due to continuous extension resulted in formation of subaereal and submarine debris flows. This was responsible for the formation of overlying volcaniclastic sequence. We believe that the arc signature was inherited from an earlier subduction event that metasomatised the sub-continental lithosphere, a process well documented in various tectonic settings such as the Basin and Range Province, the Aegean Graben System and NE Anatolia.

RCM3 : WEam13 : F3
Genesis of the Rift Volcanism and Basin Formation Related to the Opening of the Black Sea during Late Cretaceous, Western Pontides, Turkey

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A volcano-sedimentary sequence of Late Cretaceous age crops out along a long, narrow, E-W extending belt on the Black Sea coast between the towns of Cide and Inebolu (Kastamonu). It consists of a thick pile of clastic sediments intercalated with lavas and volcaniclastics. Our field observations indicate that this sequence should have been deposited in a basin which was controlled by extensive normal faulting. Palaeontologic data delimit the age of this volcano-sedimentary sequence to a period between Turonian and Campanian and this coincides with the opening of the Black Sea as a back-arc basin in the region. Rifting initiated in Turonian with an extensive volcanism. During this period, a clastic succession, known as the Derekoy formation deposited in gradually subsiding basin. Volcanism ceased between Upper Santonian and the beginning of Campanian during which pelagic sedimentation became dominant all over the region forming the Unaz formation.

We argue that this period coincides with the rupture of continental litosphere and the initiation of proto-oceanic crust of the Black Sea. During Campanian, clastic sedimentation and volcanic activity restarted producing a thick pile of coarse-grained volcaniclastic beds intercalated with relatively abundant lava flows (i.e. Cambu formation). During Maastrichtian, volcanism ceased all over the region. Our geochemical database indicates that lavas of the Derekoy formation are calc-alkaline in character (CA) and contain anhydrous fractionation phases. In contrast, lavas of the Cambu formation contain polybaric crystallisation assemblages: (1) unhydrous (POAM) and (2) hydrous (PAm: plagioclase + amphibole). Hydrous lavas of the Cambu formation are all CA in character, while those containing POAM phases are either alkaline or mildly alkaline. Subduction signature is present in all lavas including the most primitive and alkali-rich ones. Existence of this signature can either be related to (1) the inheritance from a much older subduction event, or (2) to the derivation of magmas from the metasomatised mantle source of the nearby arc. Assimilation may also contribute to LIL and LREE enrichment. Trends on trace element diagrams suggest that lavas displaying various degrees of alkalinity may be explained as mixtures of magmas derived from two different mantle sources: (1) metasomatised sub-continental lithosphere displaying a distinct subduction signature and (2) an asthenospheric source with a within plate signature. Our geochemical data are consistent with a model where magma generation is associated with lithospheric thinning which caused derivation of magma from progressively deeper zones in the mantle during the opening of Black Sea.

RCM3 : WEam14 : F3
Geochronological Constraints on Igneous Crustal Accretion along the Southeast Greenland Volcanic Rifted Margin

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The pattern of seafloor magnetic anomalies along the Southeast Greenland rifted margin is very well defined south of 66ºN and is more diffuse to the north towards the Iceland hot spot track (i.e., the Greenland-Iceland Rise, GIR). An important result of ODP drilling (Legs 152 & 163) along the 63ºN transect in the region of magnetic chron 24r (~56-53 Ma) and 18-20 km thick igneous crust was the confirmation by ^{40}Ar-^{39}Ar dating that the ages of the uppermost lavas of the seaward dipping reflector sequence (SDRS) fall within the time span of the seafloor magnetic anomaly. This correspondence is broadly consistent with the Palmasson model of crustal accretion and petrologic/geochemical studies indicating that lavas erupted from the spreading axis located east and seaward of the drilled sites. ODP drilling along the 63ºN transect also discovered an older (60-61 Ma), pre-breakup succession of lavas resting on continental basement, overlain by sediment and 56-54 Ma basalts of oceanic affinity. In 1998 and 1999 shallow water, offset drilling of SDRS's was undertaken north of 63ºN along transects at 64ºN, 65ºN, 66ºN and 68º4N in order to expand the geochronological and geochemical constraints on margin structure approaching the GIR. Offset drilling along 64ºN and 65ºN recovered pre- and syn-breakup lavas that give ages of respectively 60-59 and 56-54 Ma, correlative with 63ºN and consistent with the inferred age of the crust from seafloor spreading anomalies. However, at the GIR between 66ºN and 68ºN, the ^{40}Ar-^{39}Ar ages for lavas are notably younger (50-46 Ma), although based on the northward extrapolation of seafloor spreading anomalies and the locations of the drill sites close to line of breakup suggested these lavas should be 54-53 Ma. The new ages have large uncertainties due to the challenge of dating low-K seafloor basalt, but consistently form a group distinctly younger than expected. This lack of agreement between the seafloor magnetic signature and ages of the extrusive carapace in the vicinity of the GIR suggest a more complex history of crust accretion than found south of the GIR. Moreover, recent geochronological and geochemical studies of flood basalts from the Blosseville Kyst constrain the timing of breakup at 68ºN at 56 Ma. This shows that the northward younging of offshore lavas following the chron 24r anomaly to the GIR cannot reflect slow northward rift propagation. Rather the presence of young basalts so close to the Greenland margin north of 66ºN may indicate an increase in off-axis volcanism approaching the hot spot or relocation of the spreading axis towards plume stem. Presently, we cannot distinguish between these possibilities.