reference thickness of the transition zone, we obtained the transition zone thinner by up to 15 km beneath the stations on Tahiti, French Polynesia and that thicker by 30 km near the Tonga subduction zone. By the ScS reverberation method, we find clear signals associated to the "410-km" and "660-km" discontinuities. The transition zone thickness, which is constrained from the travel time difference between the reflection waves originated by the "410-km" and "660-km" discontinuities, is observed to be 15 km thinner beneath the South Pacific Superswell in average than the reference thickness. The result suggests that transition zone temperature beneath French Polynesia is approximately 100-200 K higher than the surrounding mantle.

T51E MC: 308 Friday 0830h

The Initiation and Early Evolution of Young Ocean Basins I *(joint with OS, S)*

Presiding: **A M Goodliffe,** University of Hawaii; **G D Karner,** Lamont Doherty Earth Observatory

T51E-01 0830h

Dynamic controls on the initiation of extension in continental and oceanic crust

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The initiation of extension depends strongly on the rheology of the nascent zone of deformation, but also on the magnitude and orientations of the applied tractions and on the crustal thickness. To investigate the importance of these effects, we construct numerical models of the evolution of zones of deformation after the imposition of applied tractions, accounting for changes in crustal or lithospheric thickness and subsequent changes in the isostatically compensated buoyancy. In oceanic systems, the buoyant torque acts to reinforce any lithospheric deformation, and the boundary either becomes predominantly divergent or completely convergent, depending on the initial loading. However there is a marked tendency for these systems to prefer evolution towards a divergent state, even when the initial loading is predominantly compressive (primarily due to an "unzipping" effect where extended crust becomes more prone to failure than contracted crust). In continental systems, the buoyant torque acts to oppose lithospheric deformation. One possible end state is that the rifting fails as the system develops a buoyant torque that matches the imposed torque, but if the imposed torque is very large it is possible for the deformation to continue and even accelerate with time. A naïve treatment of the stress gravitational potential energy suggests a buoyant torque that is absurdly large in comparison with the torques available to split continents apart from, for example, emplacement of flood basalts. A solution may be that part of the buoyant traction is transmitted elastically within the upper part of the continent, and it is wrong to include this traction in calculating the ongoing deformation.

T51E-02 0845h

Structure, Spreading Direction, Fault Formation and Caldera Control in the Ethiopian Rift

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The Ethiopian Rift is a Plio-Quaternary continental rift characterized by two interacting NE-SW trending segments. Remote sensing and field data show that the axial part of the Rift is made up of extensional fractures and open normal faults. These show a mean N50W opening direction along a distance of 400 km, indicating an overall NW-SE spreading direction between Nubia and Somalia plates. Field data and mechanical considerations suggest that when the extensional fractures in the axial part of the Rift reach critical dimensions (length about 800 m, depth about 600 m, width about 4 m), they cannot longer sustain a pure tensile behavior. Thus, the extensional fractures turn into shear fractures, becoming open normal faults at surface. Several Quaternary calderas within the Rift have an overall E-W elongation. Remote sensing and field data suggest that such elongation is controlled by pre-Rift E-W trending structures, mainly found on Nubia and Somalia plateaus. These systems have been reactivated during rifting as left-lateral faults, focusing the rise of magma and controlling the development of E-W trending magma chambers in the axial part of the rift.

T51E-03 0900h

Magmato-tectonic Evolution of Asal Rift, Afar Depression

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We investigate the relationships between magmatic and tectonic activities during rifting, taking the example of Asal, one of the most recent and active rifts of Afar. We sampled and performed combined geochemical (major and trace elements) and paleomagnetic analyses of the successive basaltic lava flows (total: 48) exposed in three of the highest (~30-80 m) normal fault escarpments, on either side of the rift inner floor and of the Fieale volcano. Previous dating suggests that lava emplaced in the rift from ~300 ka on, and the piles we analyzed between ~110 and 90 ka. The chemical analyses (48 samples) reveal that all lava was poured out from the same shallow (< a few km) reservoir. Each pile is made of two to four distinct flow sets, each ~10 to 50 m-high and having slightly, hence rapidly evolved through low pressure crystallization. The chemical evolution from one flow set to the next suggests re-feeding of the reservoir (or slight cooling of the mantle). The paleomagnetic analyses (190 samples) reveal that each flow set was erupted very rapidly, as a pulse, in less than a ~thousand years. By contrast, the entire flow piles have properly recorded the secular variation of the magnetic field, including the Blake excursion. It results that, at least between ~110 and 90 ka, the magmatic activity occurred by pulses rapidly pouring out large volumes of lavas every 10±5 ka. At the sites analyzed, the lava accumulated during each pulse at a rate of ~1-5 cm/yr, much larger than the fault slip rates. One might conclude that flows continuously covered up and erased tectonic features during rifting. However, the long time-span which separates the initiation of the present rift faults (~50±20 ka) from the latest lava flows (on rift shoulders, ~90 ka) implies that these faults did not exist before, with the possible exception of those bounding the present inner floor. Rifting therefore occurred through dominant magmatic activity, at least from ~300 to 50 ka, when normal faults started to initiate and accommodate part of the extension. Between ~300 and 90 ka, the magmatic activity seems to be mainly governed by a central volcano (Fieale). From ~90 ka on, it localizes within the present inner floor and becomes fissural. The volumes of lava which we estimate to have emplaced during these two periods of time (~20 and 10 km^3, respectively) imply a mean magmatic flux rate at the surface of $\sim 10^5 m^3/yr$, similar to the current rate (1978 Ardoukoba eruption: $\sim$10-20.10^6 m^3, recurrence time ~120-230 yr), but ~10 times smaller than the flux rate inferred at depth. Magmatic activity would therefore have also kept constant overall during rifting, although occurring through successive pulses, the major ones being supplied from at least ~10 km^3 reservoirs.

T51E-04 0915h

The Role of Detachment Faulting in the Early Evolution of Oceanic Basins

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Models of continental break-up followed by seafloor spreading conventionally juxtapose continental and oceanic crusts. However, observations from ancient and present-day ocean-continent transitions (OCT) in the Alps and Iberia provide compelling evidence that along magma-poor rifted margins these two crusts are separated by a 40 to 170 km wide zone of exhumed continental mantle (ZECM), and that the architecture and tectonic evolution of this ZECM is controlled by downward concave faults interacting with a rising asthenosphere.

In both, the Iberian and Alpine OCT zones, top-to-the-ocean low-angle detachment structures can be traced across the thinned continental crust towards oceanic crust. Although these faults accommodated ~10-20 km offsets, they caused only minor submarine relief. The occurrence of isolated allochthons of continental crust and of tectono-sedimentary breccias over mantle rocks in the ZECM shows that these mantle rocks had to be exhumed by detachment faults. Trace element compositions of mantle rocks and their local association with lower continental crust clearly support the sub-continental origin of the mantle rocks within the ZECM. Because towards the future ocean the exhumed mantle rocks appear to be derived from hotter and probably also deeper lithospheric levels, we suggest that mantle exhumation was accomplished by concave-downward faults which became active only during a final stage of rifting when the crust was already thinned to <10 km.

In Iberia, basalts have not been drilled, and geophysical data suggest little but oceanward-increasing magmatic material within the ZECM. In the Alps, gabbroic bodies, <1 km across, intruded serpentinized mantle at 161 ± 1 Ma (U-Pb zircon ages) and occur as clasts in tectono-sedimentary breccias reflecting their syn-tectonic emplacement. Pillow lavas generally become more voluminous and grade from T- to N-MORB oceanwards. Their occurrence appears to be controlled by late, syn-magmatic high-angle faults parallel to the margin. These high-angle faults cut the low-angle detachment faults responsible for the exhumation of the subcontinental mantle. The basaltic lavas represent aggregated melts of low to moderate degrees of partial melting of an asthenospheric source. Trace element compositions and Nd and Hf isotopic compositions of basalts and parental liquids of the gabbros are very similar indicating a common source.

The transition from symmetric amagmatic rifting to steady-state seafloor spreading obviously includes a transient phase of simple-shear dominated asymmetric rifting which is accompanied by magmatism. We suggest that the evolving stresses and thermal fields associated with the rise of asthenospheric mantle and the onset of magmatic activity constrain the geometry of the lithosphere-scale concave-downward faults. Finally, the ascending but narrowing asthenospheric mantle led to the focused magmatism and tectonism characterizing present-day slow-spreading mid-ocean ridges.

T51E-05 0930h

The Seismic Nature and Response of Detachment Faults in Ocean-Continent Transition Zones

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The tectonic interpretation of basement structures in seismic reflection profiles from ocean-continent transition (OCT) zones of so-called nonvolcanic or magma-poor rifted margins is notoriously difficult and ambiguous due to the scarcity of borehole information. Prominent low-angle intra-basement reflections are commonly interpreted as low-angle detachment faults and locally the top of the basement was drilled and found to represent exhumed, so-called top-basement detachment faults. However, the seismic expression of such detachment faults is poorly understood and verification by deep-sea drilling is presently limited to the very top of several basement highs.

In this paper, we compare synthetic seismic profiles from the Tasna OCT, a superbly exposed remnant of a Tethyan margin in the Eastern Swiss Alps, with seismic reflection data from the Hobby High, a drilled basement high within the present-day OCT of the Iberia Abyssal Plain. Both sites are widely considered as being representative for OCT zones of magma-poor rifted margins. The geological similarity and complementary nature of the data from both sites enable us to develop a detailed model of the seismic structure of the Tasna OCT. This in turn provides insights into the seismic imaging of OCT zones in general and of detachment

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systems in particular and thus allows for a better understanding of the architecture and tectonic evolution of OCT zones.

On the basis of the Tasna OCT models we identified some key characteristics of the seismic response from exhumed subcontinental mantle rocks, exhumed lower crustal rocks, and crust-mantle detachments. We observe (i) variable amplitudes and numerous diffractions at the top of exhumed subcontinental mantle, (ii) a continuous and strong reflection imaging the top of exhumed lower crustal rocks, and (iii) a weak and discontinuous reflection of inverse polarity representing a shallow intra-basement crust-mantle detachment. The same features are consistently observed at geologically equivalent positions in the seismic data from the Hobby High and may thus serve as guides in the interpretation of seismic data from un-drilled OCT zones.

T51E-06 0945h

Crust and Mantle Imaging Beneath Active Metamorphic Core Complexes, Woodlark Rift, Papua New Guinea

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We report here on preliminary results from a seismic experiment across the region of incipient rifting in the Woodlark Rift. In 1999-2000, we deployed 19 PASSCAL broadband seismographs across the Woodlark Rift of Papua New Guinea, in concert with offshore OBS deployments. In this region the upper crust has been removed over regionally high metamorphic core complexes (MCC's), which are bound by a set of north-dipping shear zones. The core complexes appear to be presently active, and most of the unroofing occurred within the last 2-4 Ma. Along strike 100 km to the east greater extension has led to sea-floor spreading, a geometry that produces some of the fastest localized continental extension on Earth. Two sets of seismic observations reveal a mode of extension here quite different from that seen in other rifts. First, receiver functions show 10-15 km of crustal thinning beneath the core complexes, relative to the less-extended footwall. By comparison, the Moho beneath the Basin-and-Range core complexes lies flat, which has led to models of MCC formation involving either extensive underplating or lower-crustal flow. The results from the Woodlark Rift show that a flat Moho is not universal, and that in some cases their unroofing can be accommodated below the crust. These results place limits on the rate of lower-crustal flow, and suggest that extension at rates in excess of this limit may be required for complete rifting to occur. Second, inversion of teleseismic and regional seismic travel times show a strong asymmetry of mantle structure relative to undeformed regions. At the oceanic rift tip east of the core complexes mantle seismic velocities are 5-7% slower than unrifted mantle. The low is shifted north along strike such that the low velocities lie north of the core complexes, while the mantle beneath the core complexes appears relatively fast and similar to unextended footwall. Thus, the region of inferred elevated temperatures is offset from the core complexes in a direction downdip along their bounding shear zones. These mantle velocities demonstrate a large scale asymmetry of the region of continental extension. A sharp transition must exist along strike from the relatively symmetrical sea-floor spreading in the Woodlark basin to the asymmetric continental rifting associated with the core complexes, within 100 km of the oceanic rift tip, likely reflecting a similarly sharp temporal transition in extensional style. Thus, this region of rapid continental rifting undergoes a suite of pronounced changes from asymmetric extension to crustal thinning to symmetric spreading, a transition rarely seen in one tectonic province.

T51E-07 1020h INVITED

Geology of Nascent Ocean Basins: Insights from Western Pacific Back-arc Basins and the Gulf of California

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The origin of ocean basins must involve complex interplay between heat transfer, lithosphere extension, attenuation, and rupture, and emplacement of mantle-derived melts. Petrologic details of early evolution of present Atlantic-style basins are masked by thick sedimentary prisms of passive margins. Ophiolites are lithosphere remnants from aborted ocean basins, but few seem to have originated in deep ocean. We propose that supra-subduction zone (SSZ) forearcs and backarc basins, e.g., Lau Basin, Mariana Trough, and intra-continental rifts, e.g., Salton Trough - Gulf of Calif. are analogues for two types of nascent ocean basins. In both types upwelling fertile mantle partly melts to form MORB-like crust. Silici-clastic arc/continental sediments, deposited coeval with mafic volcanics, in rift basins, is distinctive. In both settings characteristic rock age relations and petrology/chemistry are useful in recognizing them in the geologic record.

Cenozoic SSZ systems exhibit multi-stage evolution of crust/mantle owing to mantle upwelling and local extension in broad regions of crustal contraction. Volcanic island arc tholeiite (IAT) eruptions are accompanied by forearc extension, rift basins fill with silici-clastics and basalts, forearc volcanism includes boninites and IAT. These have HFSE depletion and varied LILE enrichment. MORB, IAT, Fe-Ti basalts and transitional types erupt on propagating rifts to form backarc basin crust. New volcanic arcs form outboard of backarc ridges. Remnant arc, new arc, backarc and forearc magmas may erupt nearly coeval for 5 Ma. They may be interbedded with arc-clastic rocks. The Salton Trough - Gulf of Calif. developed by mantle upwelling, coupled with crustal extension, causing continental crust thinning, detachment faults, rifting, and volcanism having varied chemistry. There is a N-S transition from extended (Basin-Range) continental crust, to inter-continental rifts having both sediments and basalt, to intra-continental ocean crust (Alarcon Rise, 23-24°N). Regionally, 40 my lithosphere extension culminated at 3.6 Ma with seafloor spreading forming N-MORB on Alarcon Rise. There is a N-S progression from mantle-derived basalts modified by extensive fractionation /crustal assimilation to N-MORB on Alarcon Rise.

T51E-08 1035h

Crustal Structure of an Active Backarc Basin at the Rift-Drift Transition: Bransfield Strait, Antarctica.

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Bransfield Strait is a backarc basin situated between the northern Antarctic Peninsula (AP) and the South Shetland Islands (SSI). Ocean bottom seismograph (OBS) data acquired in 2000 and older complementary multichannel seismic (MCS) reflection data document the crustal structure of this complex extensional basin.

Prior analysis of MCS data documents extensional structure in the upper crust, including features that are interpreted to show: (i) extension propagates from NE-to-SW; (ii) volcanics of the axial neovolcanic zone are more voluminous in the NE than in the SW; (iii) detachments may signify basinwide simple-shear extension that is in part responsible for strong basinal asymmetry; (iv) Bransfield Strait is extensively segmented along-strike.

New OBS data provide information about deeper crustal structure supporting several of these interpretations, particularly regarding propagation of rifting, distribution of magmatism, and along-strike segmentation. Data were acquired on five strike profiles, each approximately 240 km long using 11 OBSs at 20 km spacing, and three dip profiles, each approximately 150 km long using 11 OBSs at 15 km spacing. These data show (i) alternating zones of fast and slow velocity regions along strike; and (ii) spatial distribution of crustal thinning in the basin. Moho depth is constrained by observed *PmP* arrivals. Mirroring the basin's bathymetric asymmetry, Moho deepens gradually from 12-16 km beneath the axial neovolcanic zone to 18-20 km beneath the AP margin, but deepens more abruptly to 21-26 km beneath the SSI margin. The strike profiles show overall NE-to-SW deepening of Moho by 2-5 km occurring over a zone approximately 50 km wide in the central basin. This Moho geometry is consistent with NE-to-SW evolution of rifting, although crust is actually thinnest in the central basin and thickens slightly to the NE. Alternating fast-slow regions occur along strike. Fast regions appear to correlate with basement highs observed in MCS data on the AP margin, and with proximity to presumed intrusive/extrusive basalts towards the axial neovolcanic zone, while slower regions appear to correlate with half-grabens on the AP margin and ponded sediments in the axial deep. Boundaries between fast and slow regions beneath the conjugate SSI margin appear to correlate with structural boundaries between faster, older arc-related plutonic and volcanic rocks and slower, recent backarc-related volcanics and/or rifted Palaeozoic accreted forearc sediments. Using OBS, MCS, multibeam bathymetry and onshore geological observations, some structural boundaries may be traced margin-to-margin across the basin.

T51E-09 1050h INVITED

Geologic Constraints on Crustal Structure of the Upper Delfín–Tiburón Basins of the Northern Gulf of California

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Records of Pacific–North America plate motion in northwestern Mexico indicate that rapid crustal extension in the northern Gulf of California commenced during latest Miocene time. To generate 13–21 km-thick crust of the northern Gulf of California has required a substantial input of new material beyond a typical 7 km-thick oceanic crustal section. Presently, sedimentary input from the Colorado River provides a sufficient source of additional crustal material. Crustal formation prior to arrival of the Colorado River at 4.7 Ma requires input of material from alternative sources. Closely-matched ignimbrite deposits on conjugate rifted margins of the Upper Delfín–Tiburón basins indicate that the upper continental crust ruptured near the present-day coastlines of the northern Gulf of California. Thus, pure-shear type extension of the continental margin cannot have formed a substantial area of new crust in these basins. Sediment flux from other river systems of northwestern Mexico also appears to have been insufficient to generate $>$ 13 km-thick transitional crust. Exhumation of middle to lower continental crust as a metamorphic core complex may form part of the crust of the northern Gulf of California. This rifting mechanism would have added continental material to the nascent rift basin while preserving a close match of the continental surface of conjugate rift margins.

T51E-10 1105h

Oblique Rifting and the Late Transition to Seafloor Spreading in the Northern Gulf of California

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The active transform-rift plate boundary of the Gulf of California extends from the East Pacific Rise to the San Andreas Transform. In the northern Gulf of California, unlike the south, no evidence has been found for the existence of oceanic crust or seafloor magnetic anomalies. Interpretations of the style of deformation are based mainly on bathymetry, diffuse seismicity and geological and geophysical observations of the Imperial Valley and the southern Gulf. We interpret 2D high-resolution multichannel seismic data collected from May-June 1999 in the northern Gulf of California to show a broad, shallow depression encompassing multiple rift basins. This highly deformed zone consists of a complex network of predominantly NE-striking normal faults dissected in part by NW-striking oblique-normal faults. Small volcanic seamounts are located only on the youngest crust in the northern Gulf. Normal faults with seafloor offsets of tens of meters bound the major basins. Oblique faults parallel the eastern coastline of Baja California; however, their connection with the larger basins is less obvious. There is no evidence of a well-defined ridge-transform system. Based on our interpretations, deformation at the plate boundary zone in the northern Gulf is spatially distributed and the onset of seafloor spreading or localization of deformation to one spreading center has not yet occurred in this region. To understand and quantify the parameters controlling crustal deformation, we ran some 2D+1D dynamic models, which allow for the spontaneous formation of localized normal and strike-slip faults. The brittle crust is modeled as a frictional and cohesional elastic-plastic material. The ductile

middle and lower crust are modeled as non-Newtonian visco-elastic materials. Faults in the brittle layer are formed by locally lowering the cohesion as a function of strain. We vary the strength of both the brittle and ductile layers and the amount of transtensional obliquity. We find that both the amount of obliquity and the relative strength of the brittle crust vs. the lower crust control whether the deformation is localized or delocalized. Our model results are compared to the observations from the northern Gulf of California.

T51E-11 1120h

Implications for the Formation of Transform Faults from Pliocene Basins on Isla San Jose, Southern Gulf of California

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Pliocene basins on islands in the southern Gulf of California offer a superb opportunity to evaluate how transform faults form in a highly oblique plate boundary. Pliocene strata are exposed in two subbasins on Isla San Jose, 100 km north of La Paz, Mexico. The subbasins have broadly similar stratigraphy and part of the basin is subsided offshore. A $\sim$1 km thick lower sequence deepens upward from a thick alluvial fan unit through marginal marine strata to an outer shelf to upper slope mudstone (based on lithology and benthic forams). The uppermost mudstone has planktonic forams that indicate an early late Pliocene age ($\sim$3.5-3 Ma). There is evidence for widespread syn-sedimentary deformation in the lower sequence. The upper sequence is a $\sim$50 120 m thick shallow marine calcarenite that lies across a low-angle to abruptly gradational unconformity. The overall stratigraphy represents 1 1.5 km of subsidence in the lower sequence before 3 Ma, followed by local tilting of the basin and rapid upward shallowing at and after 3 Ma. A late Pliocene to Quaternary unconformity lies above the basin and most Quaternary deposits are alluvial. The southern subbasin is bounded by NW-N striking Pliocene normal and normal-dextral faults, while the northern subbasin has mainly buttress unconformities and local faults along an irregular embayment.

The subbasins on Isla San Jose may have initiated at the northern end of an early transform fault emanating from the Cerralvo trough, which suggests basin inception at 5 6 Ma. This implies a reasonable rate of subsidence for a rift basin. The rapid basin uplift indicates a major reorientation (or cessation) of Cerralvo transform faulting at $\sim$3 Ma. Mudstone deposition at 3.5 3 Ma followed by basin uplift is similar to events in the Perico basin on Isla Carmen, 120 km to the NW near Loreto. These synchronous events on two separate islands may mean that the development of early transform faults acted in unison from Loreto to the mouth of the Gulf. This implies that there was a major reorganization of early transform faults to the modern configuration at 3 Ma. In contrast, later fault reorientation in the Loreto basin at 2.4 2 Ma suggests that there may be a northward propagation of transform fault development. The evidence from the islands shows that MCS and bathymetric data from the narrow shelf are needed to resolve the connections from the basins and faults we are studying on the islands to the main plate boundary transform spreading ridge system in the middle of the Gulf of California.

T51E-12 1135h

Ocean-Continent transitions in the South Balearic Basin: Crustal Structure and Processes East of the Alboran Basin and in the South Iberian Margin

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The South Balearic and Alboran basins, behind the Gibraltar Arc, originated by continental lithosfere stretching and crustal extension mechanisms occurred in a "back-arc" setting under plate convergence contexts. Geophysical data and seismic reflection profiles provide constraints on progressive crustal thinning and decrease in lithosphere thickness from the continental Alboran Basin to the oceanic South Balearic.Basin. Structures in the transition from the stretched continental crust in the East Alboran Basin to the oceanic crust beneath the South Balearic Basin denotes that extensional deformation (detachment faults) preceded continental break-up and oceanic basement growth, which probably occurred by the late Miocene.

Extremely high magma production (from 10 to 2 Ma) characterize the Alboran-South Balearic transition, which resulted in seafloor outcropping or sub-outcropping volcanic highs. Normal faulting, with roughly E-W extension direction, and tilting may affect the oceanic basement. To the contrary, ocean-continent limits north of the western South Baleric Basin correspond to brusque boundaries that separates the oceanic crust and the stretched Alboran Crustal Domain (the thinned continental crust of the eastern Betic Cordillera in south Iberia at the Palomares and Mazarron margins). These crustal limits are active seismogenic tectonic lineaments involving high-angle normal and strike-slip faults. Major faults shaping the Palomares and Mazarron margins continue onshore within late-Miocene to Recent wrench-fault zones. Present day ocean-continent organization in the westernmost Mediterranean is be due to complex lithosphere and crustal deformation from Neogene to Present African-Europe plate convergence.

T51F MC: 121 Friday 0830h

Syn-Convergent Extension in the Apennines, Italy I *(joint with G, S, V)*

Presiding: **M Brandon,** Yale University**; D Cowan,** University of Washington

T51F-01 0830h

Geodynamic Mechanisms of Coeval Extension and Contraction With Application to the Northern Apennines

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Various models have been proposed to explain the coeval, and closely juxtaposed, extension and contraction observed in the Apennines of Italy and elsewhere. These mechanisms include: (1) gravitational collapse of pre-existing topography, (2) slab breakoff with isostatic rebound, (3) vertical extrusion of a rigid crustal block, (4) viscous spreading of a growing orogenic wedge driven by underplating or frontal accretion and (5) slab rollback with upper plate extension. We consider the applicability of these mechanisms to the northern Apennines and find difficulties in all models except the last. The principle distinguishing characteristic of the Apennines is the fact that extension has reduced the surface elevation to below sea level in the Tyrrhenian Sea, ultimately resulting in the formation of new oceanic crust. Of the mechanisms considered here, only slab retreat is capable of extending crust to this degree. Although this does not exclude other mechanisms from contributing to extension, it does strongly support the existence and importance of slab rollback in this setting.

We present a mechanical analysis of the slab rollback (retreat) model. Closely juxtaposed extension and contraction requires three kinematic components whose differential motion defines separate regions of extension and contraction. In this setting, these components are the subducting slab, the stable upper plate and a region of the upper plate which remains adjacent to the subducting slab as it retreats away from the interior of the upper plate. This third kinematic component moves relative to the stable upper plate at the rollback velocity, thus defining the region and rate of extension. Predictions of crustal deformation as a consequence of this model are demonstrated through the use of a finite element model which uses a kinematic description of the upper mantle motion as boundary conditions. Crustal deformation by plastic and viscous mechanisms is a consequence. The three-component model described above produces an orogenic wedge of steady size with one side in contraction and the other in extension. The transition is at the topographic divide, consistent with observations from the Apennines. Kinematic paths of particles which transit this orogenic wedge record a deformational history of accretion, early contraction, and late extension and exhumation, consistent with observations from the Apennines and with the moving "orogenic wave" model.

T51F-02 0845h INVITED

The Tyrrhenian Sea and the Apennines, 30 Myr of Backarc Post-Orogenic Extension

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Active extension in the Apennines and the southern Tyrrhenian Sea is the most recent event of a long process of extension which started some 30 Myr ago. Extension is the result of two superimposed phenomena, backarc extension due to the retreat of the subducting African plate and collapse of the thickened alpine crust. A migration of extension from Provence to the present-day Apennines is recognized in the geological record offshore and onshore, in the Liguro-Provenal basin, in Corsica, in the Northern Tyrrhenian Sea and in Tuscany. The eastward migration of deformation follows that of the volcanic arc.

The eastward migration of extension is contemporaneous with a migration of the thrust front. Like in the Aegean region the construction of an accretionary complex is contemporaneous with backarc rifting. Extension thus reworked the subduction complex during the eastward migration.

Extension is achieved by east-dipping shallow shear zones and normal faults. This is observed along the whole transect from Corsica to the internal Apennines where active east-dipping extensional shear zones have been recently described. Only the eastern most part of the transect shows west-dipping normal faults which reactivate earlier thrusts.

Extension started almost at the same time in the whole Mediterranean region from the Alboran region to the Aegean Sea. This drastic change in the stress regime of the backarc domains is probably a consequence of the hard collision between Africa and Eurasia 30 Myr ago which slowed down the absolute northward motion of Africa and thus favored the southward retreat of the subducting African plate. Variations in the velocity of extension through time are partly a consequence of the interaction of the subducting slab and the mantle, especially the upper-lower mantle boundary. Any mechanical model of the evolution of the Apennines should include the long-term evolution of deformation and thermal regime, as well as the complex boundary conditions imposed by the geometry of the plate boundary at the surface (oceanic subduction and continental collision zones in a small region) and by the deep behavior of the slab, not only the instantaneous deformation features.

T51F-03 0900h INVITED

Terminal Stage Subduction in the Central Mediterranean: Horizontal and Vertical Motions in a Dynamic Framework

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The overall geodynamic nature of the Mediterranean region is that of a convergent plate boundary zone, between the Eurasian and African plates. Regional scale processes, however, do not only show evidence of the expected compression but also of extension. Here we present a dynamic framework for the Tertiary evolution of the region in terms of a convergent plate boundary zone in a late to terminal stage. The landlocked basin setting concept (le Pichon, 1982) serves as a starting condition for the lithospheric processes in this stage. We use the 3D results from seismic tomography studies, numerical modelling, in combination with geological, geophysical and geodetic data to investigate how the region evolved from this starting condition. Particular emphasis is put on the central Mediterranean/ Apennines region. The vertical motions along the Apenninic foredeeps were studied in detail. They show a migrating pattern of subsidence and uplift, which is in support of migrating slab detachment as the underlying cause. The geodynamic evolution is represented as a hierarchy of processes with interconnected vertical and horziontal motions and associated