20 years. The surface breaks of the creeping Chihshang fault can be observed at the several places. A typical feature is reverse-fault-like fractures on the retaining wall. We deployed small geodetic networks across the fault zone at five sites. Each network comprises of 5 to 15 benchmarks. Trilateration measurements including angles and distances as well as leveling among the benchmarks have been carried out on an annual basis or twice a year since 1998. Compared to previous other measurements which have shown the first order creep rate for the entire fault zone, the present geodetic data provides the detailed information of the surface movements across the fault zone which usually composed of more than one fault strands and folds structures. According to our data from the local geodetic networks, we are able to reconstruct the 3-D kinematics of surface deformation across the Chihshang fault zone. Multiple fault strands are common along the Chihshang fault. Oblique shortening occurred at all sites and was characterized by a combination of thrusts, backthrust and surface warps. Strike-slip motion can also be distinguished on some fault strands. It is worth to note that the cultural feature, such as concrete basement of strong resistance, sometimes acted as deflection of surface ruptures. It should be taken into consideration for mitigation against seismic hazards.

T11F-06 1140h

Fault Slip Rates From Repeating Microearthquakes on the Chihshang Fault, Eastern Taiwan

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The Chihshang fault is the most active segment of the collision boundary between Eurasia and the Luzon arc of the Philippine Sea plate in eastern Taiwan. Seismicity study shows that the Chihshang fault is a narrow SE-dipping listric thrust extending from near surface to a depth of 25 km. Geodetic measurements indicate a 2 cm/yr surface slip rate on the Chihshang fault, however, the fault slip behavior at depth is virtually unknown. In this study we determine fault slip rates at depth by using identified clusters of repeating earthquakes with highly similar waveforms. 1487 earthquakes occurred in Chihshang area with magnitude of 1 - 6 recorded by Taiwan Seismic Network from 1991 to 2002 are used. Recurrence intervals and moment release rates from repeating earthquake sequences are analyzed to estimate fault slip rates for different sequences. Event pairs with waveform cross-correlation coefficient larger than 0.9 at two or more stations are selected as the earthquake repeaters. For the data we have processed so far, 17 repeating earthquake sequences recurred 3 to 9 times are found. Those sequences show both quasi-periodic (recurrence intervals of 0.6 - 4.3 years) and aperiodic types with magnitude range of 2.1 - 3.8 at 12 - 23 km depths. Calculated fault slip rates vary from a constant rate (2.2 cm/yr) at depths of 12 - 15 km to a gradually increase rate (4.2 - 6.5 cm/yr) from depths of 17 to 21 km. Five aperiodic sequences showing irregular recurrence intervals are likely influenced by the occurrences of nearby 1995 M5 earthquakes. The constant 2.2 cm/yr slip rate at 12 - 15 km depth range is consistent with surface creep rate (2 cm/yr) as observed from geodetic measurements. This suggests that the Chihshang fault may have a very shallow locking depth so as to allow the fault creeps freely from surface to a depth of 12 km. Future efforts will focus on completing the search for repeating earthquake sequences and calculating the subsurface slip rates on the Chihshang fault.

T11F-07 1155h

Prehistoric Earthquakes Along The Sanchiao Fault, Taipei Basin, Northern Taiwan

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Although numerous large earthquakes in Taiwan have produced surface rupture during the last century, little is known about fault slip rates and recurrence intervals of fault displacement in metropolitan Taipei city. Previous studies along the Sanchiao Fault, a major normal fault that flanks the western boundary of the Taipei Basin, suggest that the fault has a long-term slip rate of 2.3mm/yr for the past 400,000 years. The Sanchiao Fault cuts the Quaternary Sunshan Formation and contains evidence for the age of subsidence of Taipei Basin. Strata from eight boreholes were examined in order to document the late-Pleistocene-Holocene record of earthquakes along the fault. Grain size analysis, total carbon content, lithology, texture, sedimentary structures, paleosols and fossil abundance were used to correlate subsidence stratigraphic units. Woody material and detrital charcoal from the boreholes were processed to provide radiocarbon dates. Borehole SCF05 and SCF06, drilled at the northern section of the fault, show two stages of hanging wall thickening. The amount of net offset between SCF05 and SCF06 abruptly changes from 5 to 8m, implying rapid subsidence of about 3 meters at about 9.3 9.4 kyr B.P. Similarly, net offset between SCF05 and SCF06 abruptly changes about 2 m occurs at about 11.1 kyr B.P., suggesting rapid subsidence. Borehole SCF01 and SCF02, located at the central section of the Sanchiao Fault, also display similar thickening and rapid subsidence. The net offset between SCF01 and SCF02 abruptly changes from 8 to 12m, suggesting rapid subsidence of about 4 m at about 8.4 8.6 kyr B.P. Earlier subsidence at about 8.9 9.1 kyr B.P. records similar displacement. Borehole SCF14, SCF15, SCF16 and SCF17, located at the southern section of the fault and do not show substantial Holocene offset. According to our subsurface stratigraphic correlations, we suggest that the Sanchiao Fault generated episodic earthquakes during the past 10,000 years. The amount of vertical offset for each event ranges from 2 to 4.8m. If we assume that 3.5m offset represents the average surface displacement, simple scaling relationships between surface displacement to moment magnitude yields a Mw 7.1 earthquake. Damage from large magnitude earthquakes along the Sanchiao Fault would be substantially different from that produced in the 1999 Mw 7.6 Chi-Chi earthquake. A large magnitude earthquake on the Sanchiao fault would rupture eastward, directing energy into the densely populated basin.

T12A MCC: Level 1 Monday 1330h

Structure and Evolution of Nonvolcanic Rifted Margins II Posters

Presiding: **D S Sawyer,** Rice University**; K Louden,** Dalhousie University

T12A-0430 1330h POSTER

Evidence for asymmetric rifting at the Newfoundland margin from SCREECH Transect 2 wide-angle data and numerical modeling

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Recent geophysical investigations on the nonvolcanic margins of the North Atlantic have shown us that the basic structure of the two conjugate ocean-continent transitions (OCTs) is remarkably different. The evolution of the Iberian margin seems to have been controlled by a shallow low-angle fault, and mantle exhumation clearly preceded the onset of mid-ocean spreading. In contrast, no evidence for large crust-penetrating faults have been found on the Newfoundland margin, and slow-spreading oceanic crust appears to abut the edge of continental crust. These observations have been explained by development of a concave-downward detachment fault in a late stage of the continental rifting, with the Newfoundland margin representing the hanging wall of the detachment. Numerical modeling of this scenario shows that lithospheric thinning brings up hot asthenospheric mantle beneath the Newfoundland margin crust shortly before break-up. During this last phase, ductile flow of the lower crust may have formed a weld between the Newfoundland margin and incipient oceanic crust. Results from a tomographic inversion of seismic refraction data of SCREECH Transect 2 are consistent with such a sequence of events. The thinned continental crust is characterized by seismic velocities ranging from 5.4 km/s below basement to 7.0 km/s in the lowermost crust. A 3 km thick lower crustal layer pinches out towards the OCT, where upper crustal seismic velocities reach 6.4 km/s over a width of 10 km. This high velocity anomaly may be the result of lower crustal diapirism in the wake of break-up of the continental lithosphere.

T12A-0431 1330h POSTER

Seismic Characterization Of Crust On The Newfoundland Non-Volcanic Rifted Margin: Prestack Depth Migrations Of The SCREECH Survey Around ODP Leg 210 Sites 1276 And 1277

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The presence of 70 km of seismically featureless basement on the Newfoundland non-volcanic margin seaward of unambiguous continental crust and landward of recognized seafloor spreading anomalies has long fueled a debate concerning the affinity of crust within this ocean-continent transition zone. Proposed models include highly extended and intruded continental crust, slow-spreading oceanic crust, and serpentinized peridotite, each of which carries specific implications for margin formation and incipient seafloor spreading. One means of distinguishing between different crustal types is seismic reflection character. We present a grid of prestack depth migrated seismic reflection sections from the Newfoundland margin around recently drilled ODP Leg 210 Sites 1276 and 1277. Previously determined P-wave velocities and Poisson's Ratios calculated on SCREECH Transect 2 suggest the presence of over 75 km of oceanic crust on the Newfoundland margin that is not found on the conjugate Iberian margin. However, drilling at Site 1276, which lies in the transition zone, did not reach basement, so the affinity of this crust remains uncertain. Seismic and drilling investigations on the Iberian margin have revealed the presence of large tracts of exhumed, serpentinized peridotite between normal oceanic and normal continental crust. As a result, characterizing enigmatic crust on Newfoundland is essential for constraining the transition from late stage rifting to initial seafloor spreading. Drilling at Site 1276 recovered diabase sills an estimated 100-200 meters above basement. These sills typically have velocities of 5500-6000 m/s and are separated by lower velocity sediments, a small proportion of which have very slow seismic velocities and low densities (1600 m/s, 2.1 g/cc); initial shipboard work suggests that these sills might be the source of bright reflections that are found above transitional basement on SCREECH Transect 2. Large contrasts in density and velocity would be expected to generate a series of very large reflection coefficients in the lowermost sedimentary section and would likely impede signal penetration beneath the bright package of resulting reflections. Because these sills overlie a critical section of crust on the Newfoundland margin, understanding whether the featureless character results from signal penetration or properties of the crustal rocks themselves is critical to characterizing this unusual crust and thus placing constraints on the transition from amagmatic rifting to seafloor spreading.

T12A-0432 1330h POSTER

Emplacement of the Peridotite Ridge Within the Ocean-Continent Transition on the West Iberia Continental Margin

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The West Iberia continental margin began to form in the Late Triassic with the breakup of Pangea and culminated with the opening of the North Atlantic Ocean in the Early Cretaceous. While it is perhaps the best-studied continental margin in the world, the formation of a north-south segmented ridge of serpentinized peridotite located within the ocean-continent transition is not fully understood. The relatively thin sediment cover and lack of obvious volcanics make the Iberia margin an ideal place to study crustal features using seismic methods, and in 1997 the Iberia Seismic Experiment (ISE 97) collected over 4000 km of two-dimensional seismic reflection data off Iberia. Nine lines were recorded normal to the margin at a 10-25 km spacing and therefore provide cross-sections of the margin at regular intervals over a 200 km north-south distance. We prestack depth migrated the western portions of the nine margin-normal ISE 97 seismic lines. Interpretation of the depth sections suggests that the peridotite ridge is located within a broad zone of exhumed upper mantle that has been serpentinized. Total tectonic subsidence analyses provide minimum bounds on the thickness of the serpentinized layer, which extends from the zone of exhumed mantle landward under thinned continental crust. Exhumed upper mantle has previously been identified in the wider ocean-continent transition to the south in the southern Iberia Abyssal Plain, and we conclude that similar but narrower exposures occur to the north in the Galicia Bank area. While upper mantle appears to have been exhumed along all the ISE 97 lines, it does not always form a distinct basement ridge. Three ISE 97 profiles do not image a well-defined basement ridge, offering the first seismic evidence of a gap in the otherwise continuous peridotite ridge. Where it is well-developed, the peridotite ridge parallels a deeply-penetrating normal fault that developed near the end of rifting. This fault appears to penetrate into the upper mantle. We propose that this fault served as a conduit for water to localize serpentinization and cause the peridotite ridge to form diapirically within a broader zone of tectonically exhumed mantle.

T12A-0433 1330h POSTER

Numerical Modelling of the Transition from Continental Rifting to Mantle Exhumation at the West Iberia Margin.

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The continental margin of West Iberia lacks significant synrift magmatism and exhibits a zone up to 100 km wide thought to consist mainly of serpentinized and exhumed mantle between the thinned continental and the oceanic crust. However, the existence of linear magnetic anomalies pose an ambiguity regarding the exact amount of synrift magmatism produced during mantle exhumation at the surface. We investigate how the thinned continental crust gives way to a broad zone of exhumed and serpentinized mantle with little synrift magmatism. For this we use a finite element code that includes brittle and ductile deformation in both crust and mantle, production of serpentine and melt. Serpentinisation is only allowed to occur when the entire crust has become brittle so that large amounts of water can reach the mantle through brittle faults. The increase in temperature due to the exothermic nature of serpentinisation and the decrease in the coefficient of friction where serpentinisation occurs is also taken into account. Melt production includes the effect of increased depletion in mantle temperatures. In a first approximation, melt is assumed to migrate instantaneously upwards and accumulate at crustal levels. We present tests with a range of extension velocities and asthenospheric temperatures. Preliminary model runs shows how the entire crust becomes brittle after it is has reached a thickness of less than 10 km. For slow rifting velocities (< 5 mm/yr), serpentinisation occurs prior to melting, whereas for faster rifting velocities the opposite is true. In all models, crustal separation and the exposure of mantle at the continent-ocean transition (COT) occurs after the entire crust has become brittle. The relative amount of serpentinite and melt in the COT depends on the rifting velocity, with slower velocities promoting the production of more serpentinite than melt. However, for a normal mantle temperature (1300 C), even for the slow extension rate of 5 mm/yr, 3-4 km of melt should be found at shallow levels in the COT, mixed with serpentinised mantle. In order, to shut off the production of melt a lower asthenospheric temperature is required, e.g. 1200 C.

T12A-0434 1330h POSTER

Structural Evolution and Rift History Leading to Breakup at the Deep Galicia Margin .

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The Deep Galicia margin is a classic example of non-volcanic margin and was the first where unroofed mantle rocks (the Peridotite Ridge) and a detachment fault (S) were recognised. We have completed the prestack depth migration of in total eight sub-parallel profiles across the margin, which reveal the fault block structure in unprecedented detail. In addition, we have depth migrated seismic profiles across the Galicia Interior Basin, providing an overview of the structure and evolution of the entire margin. In this poster, we summarise the main results, presenting depth sections, velocity sections and structural restorations across the margin. The sections reveal the tilted fault block structure of the margin. In the most recent sections, it can however be seen that the sediment tilted within the fault block occurs in at least two orientations, implying multiple phases of faulting. Some of these earlier faults may be imaged as short segments offset by the latest set of block-bounding faults. Restoring the latest phase of extension aligns the earlier structures and allows more detailed analysis of the structural history of the margin. Together with the depth images and structural reconstructions, the stratigraphic evolution as determined by drilling and submersible sampling constrains the rift history of the margin. Rifting started in the Berriasian, resulting in the drowning of Tithonian carbonate platforms and producing deep-water conditions for subsequent deposition. A second phase of rifting in the Valanginian-Hauterivian was accompanied by the deposition of locally thick sequences of deep water clastics. As these are thicker in the south than the north, extension may not have been east-west. The third phase of faulting, producing the tilted fault block structure that is imaged, probably occurred between the Barremian-Aptian, but may have migrated westwards as a rolling hinge system, consistent with the geometries of the latest phase of faulting.

T12A-0435 1330h POSTER

The Porcupine Basin (west of Ireland): Asymmetric Detachment Tectonics and Mantle Serpentinisation. Implications for the Structure and Evolution of Conjugate Non-Volcanic Rifted Margins

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The Porcupine Basin, south-west of Ireland, provides an opportunity to investigate the symmetry and temporal development of extension processes leading to continental breakup. The axial stretching factors derived from subsidence increase from 1.5 (typical values of the North Sea) in the north of the basin up to values greater than 6 (typical for continental margins) in the south. Actual stretching factors are likely to be even larger if the mantle underlying the crust has been partially serpentinised. For this reason a series of seismic profiles across the basin can show how a rift evolves to a completely developed continental margin. Furthermore, both sides of the basin may be imaged during one survey, allowing the investigation of symmetry/asymmetry of extension. We have addressed these issues by pre-stack depth migration selected seismic profiles to provide depth images across the basin at different latitudes. These allow structural analysis of the effects of progressive extension. Together with the analysis of reflection characteristics (polarity, waveform, amplitude) allows an integrated interpretation of the basin. A bright reflection (P) appears to represent a detachment fault, and may in part follow the top of partially serpentinised mantle. This is consistent with results from gravity modelling, and with the models of crustal embrittlement and mantle serpentinisation during extension. We infer that this detachment developed as part of a rolling hinge system, with late extension migrating westward. Although overall the basin remains symmetric, the consistent westward structural dip of the detachment implies that, at high stretching factors, extension was asymmetric. We might thus expect considerable differences in the late-stage evolution of conjugate margin pairs, such as Iberia and Newfoundland.

T12A-0436 1330h POSTER

North Atlantic Rifted Margin Crustal Thickness and Crustal Thinning from Satellite Gravity Data

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Crustal thickness has been derived from satellite gravity data for the North Atlantic between 50 and 70 degrees N in order to determine rifted margin crustal thinning. Satellite derived gravity anomaly data (Smith & Sandwell 1997) and bathymetry data (Gebco 2003) are used to derive the mantle residual gravity anomaly which is then inverted to give Moho depth. The gravity anomaly inversion to determine Moho depth is carried out in 3D in the spectral domain. Oceanic lithosphere and stretched continental margin lithosphere contain a large negative residual thermal gravity anomaly (up to - 380 mgal) which must be corrected for in order to determine Moho depth. This thermal gravity correction may be determined for oceanic lithosphere using oceanic isochron data, and for the thinned continental margin lithosphere using margin rift age and beta stretching estimates iteratively derived from crustal basement thickness determined from the gravity inversion. Beta stretching estimates and the thermal correction rapidly converge within a few iterations. The use of the thermal correction within the gravity inversion has been tested by producing profiles of derived crustal thickness running across the mid-Atlantic Ridge from Hatton and Edoras Banks to their East Greenland conjugate margins. The gravity inversion using the thermal gravity correction predicts oceanic crustal thicknesses consistent with seismic observations, while that without the thermal correction predicts much too great oceanic crustal thicknesses. Because of errors in the location of the ocean-continent transition within the oceanic isochron data set, two approaches may be used to define the thermal gravity correction for the determination of rifted margin crustal thickness. In option 1, oceanic isochron data is used to define the location of the COB, the oceanic lithosphere beta stretching factor is assumed to be infinity, and ocean isochron data is used to define oceanic age for the calculation of the thermal gravity anomaly correction. Option 1 has the advantage that it correctly predicts increasing thermal gravity anomaly correction towards the ocean ridge, but the disadvantage that it unrealistically assumes that oceanic isochrons (and therefore the COB) are accurately known. In option 2, the oceanic isochron data is ignored and is not used to define the COB, and the thermal gravity correction is determined in a similar way to that for continental lithosphere by using the rift age specified for continental breakup and lithosphere beta stretching factors derived from crustal basement thickness from gravity inversion. Option 2 has the advantage that it does not assume the location of the COB, but the disadvantage that it fails to predict increasing thermal gravity correction towards the ocean ridge, and as a consequence incorrectly predicts thickening of oceanic crust with decreasing oceanic age. In the absence of reliable sediment thickness data, sediment thickness is assumed to be zero giving an upper bound of Moho depth, crustal basement thickness and continental beta stretching factor. In the absence of seismic estimates of volcanic addition thickness (magmatic underplating) for continental margin crust, volcanic addition is assumed to be zero also giving a lower bound of continental beta stretching factor.

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T12A-0437 1330h POSTER

Diffuse Extension and the Formation of Non-Volcanic Mesozoic Rift Basins in the Northeast Atlantic

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Mesozoic rifting associated with regionally diffuse lithospheric extension occurred across the North Atlantic region and typically led to the formation of non-volcanic rift basins and margins. The deformation occurred over normal temperature or cooler asthenosphere at low strain rates and involved components of pure and simple shear. Two end-member sedimentary basin types are recognized as part of a kinematically coherent system of elements within the extended lithosphere between eastern North America and the European platform. These are compartmentalized by transfer/transform faults. The deep water Rockall and Porcupine Basins overlie lithosphere where large amounts of strain was focused into the upper-mid crust producing greater amounts of syn-tectonic subsidence. Abrupt discontinuities in the velocity field across regional transform fractures generated rotational strains in the southern Rockall and Porcupine Basins, while in the Celtic/Irish Sea Basins the stretching is lower (typically $\beta < 2$) and the strain field is largely translational. The cool thermal regime and the low strain rate inhibited basaltic melt production and led to the embrittlement of the upper lithosphere. The deformation drove seawater circulation and the exhumation and serpentinisation of mantle peridotites particularly along the regional transform fractures linking both the Porcupine and Rockall Basins. Strengthening of the lithosphere during this early phase of diffuse regional extension in the North Atlantic may have caused changes in the pattern of plate motion and mantle convection in the mid to late Cretaceous.

T12A-0438 1330h POSTER

Crustal Structure and Continental Break-up Revealed From Multichannel Seismic Data Across the North Biscay Rifted Margin.

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The North Biscay margin is a non-volcanic rifted margin that extends for ~400 km along strike between the Amercian margin to the east and the fossil Bay of Biscay triple junction and Goban Spur to the west. Rifting occured during the late Cretaceous (~100 Ma), at the same time as Goban Spur in the north Atlantic. No syn-rift volcanism is observed and an abrupt transition to oceanic crustal spreading has been previously interpreted. A well defined reflector ('S') can be seen near the seaward tip of continental crust and is continuous for at least 160 km along margin strike. Towards the eastern part of the margin 'S' can be identified in thinned continental crust up to ~15 km thick. We present reprocessed data from a 200 km, 24 fold multichannel seismic reflection line, CM13, acquired in 1977 over the western part of the margin. Stacking velocity analysis was performed every 2.5 km and tau-p multiple removal applied pre-stack. Post-stack time migration was carried out based on a smoothed stacking velocity model. Tilted continental fault blocks are large (up to 30 km wide) and draped by Tertiary to recent sediments. Clear pre- and syn-rift sediments are visible over the largest block which is bounded to the south by a strong reflector which rapidly flattens and is overlain by 1 s TWT of seismically transparent basement, forming a broad zone ~40 km wide. Beneath this, at ~9 s TWT, is a continentward dipping package of reflectors that may represent the Moho. Further seaward lie three smaller (10-15 km) fault blocks, separated from the other continental blocks by the transparent basement. The bounding fault of the most seaward of these blocks soles out 0.4 s TWT within basement at the 'S' reflector which is raised towards top basement and dips continentward. Overlying the southern portion of 'S' is thin upper basement (1 s TWT), seismically distinct from the adjacent thinned continental crust which may represent initial oceanic crust. A -100 nT magnetic anomaly marks this boundary and basement is magnetically quiet for ~80 km until the first marine magnetic anomaly, 34, is reached.

T12A-0439 1330h POSTER

How Synthetic Fault Arrays and Missing Lower Crust Support Symmetric Rifting Models

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Continental rifts are often associated with synthetic normal faults generally dipping towards the rift center where rifting has proceeded to seafloor spreading. We use an advanced numerical technique to study the formation of these fault arrays. The model has a particular vertical and horizontal strength stratification. It consists of upper crust, lower crust and mantle. The upper crust comprises a brittle upper layer and a weak plastic lower layer. The lower crust and the upper mantle deform through temperature dependent viscous creep and are strong enough not to flow into the rift center. In the center, the model has a pronounced thermal perturbation, which acts as a weak spot in the lower crust and mantle. The formation of synthetic faults requires a consistent shear stress at the base of the brittle layer. In our model, such a shear stress arises, because the brittle portion of the upper crust responds differently to extension than the strong deeper layers of the lithosphere. The predefined perturbation in the thermal structure triggers strain localization in the lower crust and mantle, as the higher extension rate at this weak site sucks up hot mantle and further increases the thermal anomaly. In the brittle upper crust deformation is accommodated through normal faulting. Slips along individual fault planes originate topographic and elastic stresses in the surrounding rocks. If this effect outweighs strain weakening on existing faults, new faults appear and deformation distributes. Hence, the lower crust and the uppermost mantle can widen at a single place, whereas the brittle upper crust undergoes a more regional collapse. This deformation geometry causes a horizontal shear stress towards the necking area in the lower layers. Therefore, faults in the brittle upper crust consistently dip towards the rift center on both sides of the rift. The weak layer in the upper crust accommodates large strain, as it transfers the distributed deformation in the brittle layer horizontally into the necking area below. The opening gap in the center is filled with uprising mantle from below and with collapsing upper crust from above. Therefore, upper crustal rocks come to rest directly on top of mantle rocks with no lower crust in-between. Our model is symmetric at a lithospheric scale. The calculations reproduce the three main characteristics of non-volcanic margins such as the Iberian Margin: (1) At the tip of the continent upper crust rests directly on top of exhumed mantle on both sides of the rift with no substantial lower crust within some tens of kilometers of the distal margin. (2) The upper crust is defined by an oceanward dipping fault array and tilted blocks. (3) A prominent sub-horizontal ductile high strain zone, the s-reflector, is present at the base of the upper crust.

T12A-0440 1330h POSTER

Modelling Sea Floor Spreading Initiation and Depth Dependent Stretching at Rifted Continental Margins

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Depth dependent stretching, in which upper crustal extension is much less than that of the lower crust and lithospheric mantle, has been observed at both non-volcanic and volcanic margins and is not predicted by existing quantitative models of rifted margin formation which are usually based on intra-continental rift models subjected to very large stretching factors. New conceptual and quantitative models of rifted margin formation are required. The timing of depth dependent stretching on the Norwegian margin suggests that depth dependent stretching of continental rifted margin lithosphere occurs during early sea-floor spreading rather than during pre-breakup rifting. These observations suggest that the main thinning of rifted margin lithosphere occurs during early sea-floor spreading rather than during pre-breakup rifting. Single-phase fluid-flow models have been applied successfully to sea-floor spreading at ocean ridges. A single-phase fluid-flow model of sea-floor spreading initiation has been developed to determine rifted continental margin lithosphere thinning and thermal evolution resulting from early sea-floor spreading. The ocean-ridge initiation model uses an isoviscous corner-flow stream-function solution (Batchelor 1967) to predict the divergent lithospheric and asthenospheric fluid-flow field associated with early sea-floor spreading. The thinning of the rifted continental lithosphere is calculated by material advection in the newly initiated ocean ridge fluid-flow field. The model may also include the effects of pre-breakup pure-shear stretching of continental lithosphere. Rifted margin lithosphere thinning and thermal evolution is dependent on ocean-ridge spreading rate (Vx), the mantle upwelling velocity beneath the ridge axis (Vz), and the pre-breakup lithosphere beta stretching factor. The developed model predicts the thinning of the upper crust, lower crust and lithospheric mantle of the continental margin, and the history of rifted margin subsidence, water depths and top basement heat-flow. The ocean-ridge fluid-flow models predict advection of continental lithosphere material and depth dependent stretching which is highly sensitive to the ratio of Vz/Vx. Convection modelling of sea-floor spreading initiation at volcanic margins (Nielsen & Hopper 2002) suggests that Vz/Vx > 5 for early sea-floor spreading, reducing to Vz/Vx 1.3 after a few Ma. Application of this Vz/Vx history predicts that lower continental crust and lithospheric mantle adjacent to the site of sea-floor spreading initiation is advected continentward producing a distribution of depth dependent stretching consistent with that observed at volcanic margins. Mantle exhumation is not predicted for Vz/Vx $\gg$1. For non-volcanic margins, Vz/Vx at sea-floor spreading initiation is expected to be 1. Models of sea-floor spreading initiation with Vz/Vx 1 predict that lower continental crust and continental lithospheric mantle adjacent to the site of sea-floor spreading initiation are advected oceanward and result in rifted margin depth dependent stretching and continental mantle exhumation consistent with that observed at non-volcanic margins.

T12A-0441 1330h POSTER

Preliminary Insights to the Crust and Upper Mantle Structure of the northern Seychelles Continental Margin.

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Marine geophysical profiles were collected over the conjugate Seychelles - Laxmi Ridge pair of rifted continental margins during Charles Darwin cruise 144 in Jan/Feb 2003. The aim was to obtain data from an initially fast-spreading rift (half rate 59 mm/yr) to constrain modelling of strain rate and its effect on passive margin structure. The margins were restored using seafloor spreading isochrons and a single transect was designed across the entire reconstructed rift avoiding fracture zones and seamounts. Here we present preliminary results from the Seychelles margin. The Seychelles islands consist principally of pre-Cambrian granite surrounded by a carbonate platform. The transect extends north of Mahé, over the shallow water plateau and into the deep-water Eastern Somali Basin (1.5-5°S, 55-57.5°E). The line extends beyond magnetic anomaly A27 onto undisputed oceanic crust. Wide angle and multi-channel seismic (MCS) data were obtained along a 300 km NNE/SSW line, and an additional 800 km of MCS data were also collected in the area. These MCS profiles were acquired using a 96-channel, 2.4 km-long streamer and a 6920 cu in airgun array fired every 60 s for the main line and a 3890 cu in, 30 s array for the extra MCS lines. 32 GEOMAR OBS were deployed along the main line and 21 Leeds/Potsdam land seismometers on the islands for the wide-angle work. Gravity, magnetics, swath bathymetry and dredge samples were also collected. The Moho is widely imaged on brute stacks of the MCS profiles beneath the deep-water part of the transect. Its character changes from flat and smooth on the ocean side to a more complex and layered form towards the continent. The crustal thickness appears to thicken from about 6 km to 14 km over a horizontal distance of 8 km, before the Moho image is lost beneath the rough platform edge. A narrow package of seaward-dipping reflectors is evident under sediments off the edge of the platform with 15-20° dip and 16 km length. Several prominent seamounts were imaged using swath bathymetry within the ocean-continent zone. Three of these were dredged, and yielded basalts erupted from shallow marine or subaerial environments. The wide-angle data, from both OBS and landstations, recorded Pn arrivals at the furthest distance possible (300 km).

First arrival travel times were picked and used in FAST to create a preliminary velocity model of the continental margin.

T12A-0442 1330h POSTER

Structure of the Laxmi Ridge Ocean-Continent Transition Zone

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Seismic profiles were acquired in Jan-Feb 2003 across a pair of conjugate rifted margins in the NW Indian Ocean. These margins are thought to have formed under significantly higher strain rate (59mm/a half-rate) than the much studied Atlantic Margins, which typically separated at ~10-20mm/a half-rate. Here we present results from the northern study area - the Laxmi Ridge continental margin. Our long-term aim is to investigate the influence of extensional strain rate on rift architecture and magmatism. Laxmi Ridge is a NW-SE trending basement high. It is 200km at its widest point, extends for 1200km, and rises up to 1400m above the background basement relief. Free-air gravity models suggest it consists of continental crust. South of Laxmi Ridge there are undisputed sea floor spreading anomalies; as old as Chron 27. The northern limit of Laxmi Ridge abuts Gop Rift. Within Gop Rift the magnetic field consists of a series of high-amplitude, linear, positive and negative SSE-NNW trending anomalies whose origin is currently unresolved. We collected data from Chron 27 to the continental rise north of Gop Rift. The main profile trends N-S for 480km. 32 ocean bottom instruments recorded shots from a 6920cu.in airgun source, fired every 60s. Coincident MCS profiles were recorded with a 2.4km 96-channel streamer, and part of the main line was reshot with a 3890cu.in source, fired every 30s. A preliminary velocity structure of the Laxmi Ridge margin has been generated from tomographic inversion of first arrivals seen out to offsets of 70km; uncertainties are 20ms for close ranges, <200ms for offsets >50km. Generally, the crust thins to the south and Pn arrivals indicate a crustal thickness of 7km seaward of Laxmi Ridge. A bright package of reflections ~200ms twt thick covers the Gop Rift and oceanic basement surfaces. It is laterally discontinuous, and thickens to ~300ms in basins. Seaward-dipping intrabasement reflectors are seen for ~100km south of the crest of Laxmi Ridge.

T12A-0443 1330h POSTER

The Seismic and gravimetric characteristics of the Luzon-Ryukyu Transform Fault, a boundary between the Southeast Asian continental margin and the South China Sea oceanic crust

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The northernmost oceanic crust of the South China Sea (SCS) is bounded by the Eurasian continental margin in the northwest, the Taiwan island in the northeast and the Manila Trench in the east. Based on magnetic anomalies, the oceanic crust of the northernmost SCS is terminated by a NW-SE trending transform fault, called the Luzon-Ryukyu Transform Fault (LRTF). The LRTF is supposed to connect the former Ryukyu Trench in the northwest and the former Manila Trench in the southeast. The northwest part of the LRTF is marked by the linear topographic escarpment, along which the Formosa Canyon has developed. Here we use 14 multi-channel seismic reflection profiles to study the crustal structures around the LRTF. To better understand the deep crustal structure, we also perform a gravity modelling to estimate the depth variations of the Moho surface. The results show that in the NW area of the LRTF, the volcanic basement is gradually deeper to the northeast. And, the sediment thickness varies from 1.5 3 twt in the southwest side of the LRTF to 2.5 4 twt in the northeast side. In the SE area of the LRTF, the basement offset of about 1.5 twt is clearly observed. The overlying sediments of about 0.5 1 twt thick have subsided differentially on both sides of the LRTF. Based on calculated bouguer gravity anomaly, a high anomaly (up to 100 mGal) in this area is observed, which implies a thin crust feature and similar crust characteristics on the both sides of the southern LRTF area. The only obviously fractured volcanic basement, indicating the existence of a transform fault or fracture zone, is observed in the SE end of the LRTF, close to the Manila Trench. The absence of fractured basement along the other part of the LRTF is probably due to the intrusion of the later volcanic activities.

T12A-0444 1330h POSTER

The crustal structures of the continent-ocean transition zone in the northern South China Sea

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The continent-ocean Boundary (COB) in the northern South China Sea (SCS) was suggested to be almost along a 3000m-isobath near the northern continental slope. According to the magnetic anomaly identification, the age of the South China Sea oceanic crust is about 30 to 15 Ma and the northernmost oceanic crust is distributed near 18°30'N. To the north, due to lack of good correlated magnetic data and deep seismic profiles, most studies do not suggest the existence of the oceanic crust. However, new magnetic evidence indicates that the oceanic crust may extend to 21°30'N. In this study, we carried out a synthesis of the existing seismic reflection profiles across the COB zone. We also used the corresponding gravity anomalies and a simple four-layer crustal model to simulate the depth variation of the Moho discontinuity across the SCS northern margin. Based on our results, we can distinguish the SCS northern margin into three portions: the western, the middle and the eastern portions. In the western portion, our crustal models show a good agreement with the previous studies. The COB follows the 3000m-isobath and a continent-ocean transition zone (COT) spreads ca.150-250 km wide. In the eastern portion, our models bring out completely new insights. We find that the COB is close to the continental shelf and is along ca 2000m-isobath. The crustal pattern from continental to oceanic has changed quickly. The COT is much narrower than the western portion. The middle portion, including the Dongsha Rise, seems to be a high platform and comprises many intruded or extruded igneous bodies, revealed by bathymetry and seismic data. This phenomenon is quite different from the other two potions of the study area. Our results show the crustal thickness below this region is still thin (ca. 8-9 km close to normal oceanic crust thickness) but is thicker than surrounding area. We suggest that the igneous events have affected the original oceanic crust, which provides a possible mechanism for the formation of the Dongsha Rise. The range of COT is about 200 km in this portion.

T12A-0445 1330h POSTER

Geological Constraints and Numerical Models of Concave-downward Normal Faulting and Metamorphic Core Complex Formation in Eastern Papua New Guinea

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The Owen Stanley fault system (OSFS) is a regional, normal to transpressive plate boundary fault zone that traverses the entire 600 km length of the Papuan Peninsula and has controlled the location and Plio-Pleistocene uplift history of metamorphic core complexes (MCC's) in the Dayman-Suckling massif and on the D'Entrecasteaux Islands. Near the eastern end of the peninsula, the Gwoira fault zone of the OSFZ is well exposed as an exhumed, striated, concave-downward normal fault surface across the Dayman-Suckling MCC. The Gwoira fault plane dips north at an angle of 15°; megastriations on the fault plane indicate dipslip displacement; earthquake focal mechanisms constrain active, north-south dipslip extension; GPS measurements constrain extension rates of 19 mm/yr. Pliocene-age marine sedimentary rocks entrained as a coherent, 170 km^2 sheet on the fault plane constrain its post-Pliocene dipslip motion. The 25-32 km length of the exhumed Gwoira fault plane exposed across the Dayman-Suckling MCC provides a minimum estimate for offset along the normal fault. The footwall block is characterized by high topography up to 2-4 km at the crest of the Papuan Peninsula, Holocene coral reefs uplifted at rates of 4.3 mm/yr, and flights of terraces along deeply incised river valleys. The hanging wall block is occupied by a low relief coastal plain and a half-graben structure underlying Goodenough Bay (water depth: 1 km; 1.2 km of Miocene-recent sedimentary fill). In order to understand the relationship between this fault and now subsiding MCC's located 80 km north of the Gwoira fault zone in the D'Entrecasteaux Islands, we present three numerical models that simulate three possible physical processes previously proposed for this area or for analogous areas: 1) extension controlled and focussed by crustal diapirism of a lower density and viscous lower crust; modeling predicts a crustal diapir ascending from a mid-crustal, low density layer; 2) mantle exhumation is controlled by a lithosphere-penetrating rolling hinge; modeling predicts an asymmetrical rolling hinge at a concave-upward normal fault after 10's of kms of low-angle fault offset; and 3) extension is dominated by active mantle upwelling.

T12A-0446 1330h POSTER

Seismic Velocities Across a Region of Continental Breakup, Woodlark Basin, Papua New Guinea

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The Woodlark Basin rift system is one of the fastest opening continental rifts on the planet and along strike shows the full progression from continental rifting to sea-floor spreading. Seismic velocities provide information on the extent of mafic additions to the crust with increasing rifting. We report on the results from P and S wave velocity tomography across an area 350 by 350 km surrounding active metamorphic core complexes and the spreading tip. Data from 1167 local earthquakes recorded during 1999-2000 by 19 onshore PASSCAL broadband and 14 offshore OBS/OBH instruments are used to jointly solve for hypocenters and velocities. The continental crust landward of the spreading tip and around the core complexes shows uniformly low velocities of 5.9-6.4 throughout the upper 25 km. These velocities indicate felsic crust and preclude significant thickness of ophiolitic material or significant mafic additions to the crust. Near the active spreading tip velocities are 2-6% faster. This most likely reflects the thinner, more mafic crust associated with the spreading tip.Upper mantle velocities are reached by 25 km depth here, while the more continental regions still show lower crustal velocities to 35 km. The relocated hypocenters define more tightly defined clusters than with initial 1D models. The majority of seismicity appears northwest of the spreading tip, following a graben structure identified on high-resolution bathymetry. Large teleseismic earthquakes have been located near here, and the graben may represent the main normal fault system accommodating extension. Preliminary locations favor a north dip to this fault system parallel to the inferred low-angle fault planes, although the hypocentral uncertainties are large.

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T12A-0447 1330h POSTER

Tectonic evolution of the Coulman High and Central Trough along the Ross Ice Shelf, Southwestern Ross Sea, Antarctica

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In Cretaceous time, rifting of the New Zealand subcontinents from the Ross Sea Sector of Antarctica resulted in the formation of passive margins and widespread extension throughout the Ross Sea Embayment. This rifting event is thought to have produced widespread basin and range topography throughout the Ross Sea. More specifically, Cretaceous extension has been interpreted with confidence in the Eastern Basin of the Ross Sea but not in the western Ross Sea. In January of 2003, new geophysical data were collected on board RVIB Nathaniel B. Palmer cruise NBP03-01 along the Ross Ice Shelf front, Antarctica. The primary goal was to collect detailed grids of seismic data to select potential drill sites to further understand the glacial and tectonic history of the Ross Embayment. The survey sites were located in regions where large sections of the ice shelf have recently broken off, thus exposing previously covered and unexplored seafloor. Because the ice shelf is advancing at 1 km/yr, drilling from the ice shelf into the survey area will be possible in 2 to 3 years. The C-19 survey site in the western Ross Sea was uncovered by the breaking off of the C-19 iceberg in March of 2002, and includes approximately 3600 km2. It spans from the Victoria Land Basin (VLB) immediately west of the survey site to the Coulman High, over the Central Trough and west onto the Central High. The multichannel seismic reflection data have been processed, for attenuation of multiples. The resulting stacks have been loaded and interpreted in 3D interactive software. The data collected from the survey site shows well-defined N-S trending normal separation faults. Regional correlation along several different paths from coreholes near Cape Roberts in the western Victoria Land Basin, have been made to the C-19 survey site. Although this correlation crosses many faults, it suggests that a 23 Ma horizon is within a few hundred meters of the seafloor at the C-19 survey area. We interpret two unconformities below the 23 Ma horizon. The first unconformity overlies gently tilted and faulted strata, which we interpret as early Oligocene in age. The second and deeper unconformity overlies tilted and highly disrupted or discontinuous strata, which we interpret as Cretaceous syn-rift deposits. Given the fact that we have correlated a Miocene horizon to the survey site, our interpretation of Cretaceous syn-rift strata and early to mid Cenozoic extension is permissible. Similar interpretations have been made in the Eastern Basin of the Ross Sea and are widely accepted. We propose these interpretations are not unique to either the Eastern Basin or the C-19 region. We suggest that highly disrupted Cretaceous syn-rift deposits overlain by gently tilted and faulted strata are characteristic of and occur across the entire Ross Sea.

T12A-0448 1330h POSTER

TECTONIC FEATURES OF THE BARGUZIN DEPRESSION OF THE BAIKAL RIFT ZONE USING COMPUTER INTERPRETATION OF ELECTRICAL SOUNDINGS DATA

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In 1950s of the twentieth century, extensive geophysical prospecting was carried out in the region of Baikal Rift Zone with the aim to investigate the deep depression structure. The basic method of geophysical exploration was vertical electrical sounding (VES). At that time, the sufficiently complicated structure of the section gave no way of determining the main parameters of separate depositional sequences. With the development of computer techniques it has become the possibility to interpret these complicated data of electrical exploration at the new qualitative level by using programs of mathematical modelling and inversion. At the first stage, interpretation of electrical prospecting data was executed based on solution of the inverse problem within the limit of the horizontally-layered model using the SONET program complex. Moreover, by using both 2D modelling and inversion, it is possible to refine geoelectrical parameters and to conclude that entirely acceptable results can be obtained using 1D inversion. The final results reflect the detailed deep depression structure and it tectonic features. Tectonically active zone with multiple ruptures, which form complicated block structures as in the sedimentary cover so in the base, are under investigation.The sedimentary cover is as thick as 2.5 km according to results of computer interpretation. Fractured zones exhibit the areas with decreased rock resistivity. Reconstruction of a detailed tectonic structure of Barguzin depressions allow better understanding peculiarities of geodynamic processes for the Baikal rift zone in general and for depression in particular.

T12A-0449 1330h POSTER

The structure and evolution of Baffin Bay and its implication on the development of the continental margins of northwest Greenland, the Nares Strait, and Baffin Island, Canada

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Baffin Bay, located between northern Greenland and North America, is an ocean basin with a poorly understood seafloor spreading history. Magnetic anomalies identified in the North Atlantic, Norwegian-Greenland Sea and Labrador Sea have defined the independent motion of the Greenland Plate during the Cretaceous and Tertiary. However, defining the age and geometry of the crustal rocks of Baffin Bay remains key to understanding the plate tectonic history of the North Atlantic and Arctic Ocean. Satellite derived gravity data over Baffin Bay have revealed an axial low with large offsets that has been interpreted as an extinct spreading ridge and transform fault system, and this geometry has been used to improve the rotation pole for Greenland relative to North America. Based on the timing of a change in the direction of plate motions in the Labrador Sea, the latest phase of the spreading system in Baffin Bay is assumed to have been active between chron 24R (55Ma) and 13N (35Ma). Since no recent magnetic data exist in the Baffin Bay area, and older surveys suffer from the extremely large diurnal effects, observed in the auroral zone, the independent dating of the rift system remains enigmatic. However, Jackson et al. (Can. J. Earth Sci., 1979) report a magnetic survey corrected with independent diurnal observations from a moored magnetometer. A re-evaluation of this data, in context with the identified spreading system, reveals the existence of linear magnetic anomalies consistent with patterns of seafloor spreading, proving an oceanic character of the basin. The identified anomalies are tentatively interpreted as magnetic chrons 25N and 26N, and provide the first definitive ages of the plate geometry within Baffin Bay. Modern aeromagnetic data collected in the Nares Strait region in 2001 and 2003, in collaboration between the German Federal Institute of for Geosciences and Natural Resources (BGR) and the Geological Survey of Canada (GSC) have revealed new insights into the geometry of the plate boundaries between Canada and Greenland, implying that a simple linear Wegener fault along Nares Strait is likely not valid. Questions that remain unsolved, and for which a variety of hypotheses have been proposed include: Did Greenland behave as one plate during the Cenozoic or was it acting as at least two distinct plates; How much displacement took place along Nares Strait; How is the opening of Baffin Bay related to the development of the Sverdrup Basin? We present reconstructions of compiled magnetic, gravity, and bathymetric data between Canada and Greenland (Oakey et. al, 2001) to show how the evolution of Baffin Bay relates to the opening of the North Atlantic as a whole, and speculate on how the early opening history affected the evolution of the conjugate continental margins of northwest Greenland, Nares Strait, and Baffin Island, Canada.

T12A-0450 1330h POSTER

Differing Forms of Continental Rifting on the Eurasian and Amerasian Margins of the Lomonosov Ridge, Arctic Ocean

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The Lomonosov Ridge is a high-standing ridge of continental crust extending across the Arctic Ocean, separating the Amerasian and Eurasian Basins, and forming a continental margin to both basins. Geophysical data collected from U.S. Navy submarines during the SCICEX program shows that the Lomonosov Ridge has a different structural relationship to each of the flanking basins. These variations appear to reflect two very different types of rifting and resulting continental margins. The western Lomonosov Ridge is steep, blocky and less than 100 km wide for 450 km from the North American margin past the pole. This portion of the ridge is made up of sets of tilted fault blocks forming sediment-filled half grabens. South of 88°N on the Eurasian side, the ridge broadens to about 200 km width. The Eurasian side of the ridge remains steep and relatively straight to the Siberian slope. The majority of the broadening occurs on the Amerasian side which consists of a series of en echelon ridges oriented at about 30° to the overall trend of the ridge. The Lomonosov Ridge is flanked on the Eurasian side by a 40-60 mGal free-water gravity low relative to the level in the Eurasian Basin, generally with a steep gradient on the basinward side of the low. The gravity gradient parallels and is located just ridgeward of the termination of the Cenozoic seafloor magnetic anomaly sequence in the Eurasian Basin and is interpreted as the ocean-continent boundary. The parallelism between the Lomonosov Ridge, the magnetic anomaly trend and the present Gakkel Ridge axis along much of the length of the Eurasian Basin implies nearly orthogonal rifting. The blocky Greenland end of the Lomonosov Ridge is paralleled on the Amerasian side by Marvin Spur, which can be traced as a narrow, linear ridge or as a gravity high across the Makarov Basin to about 88°N on the Siberian side, where the Lomonosov Ridge broadens and becomes more complex. Marvin Spur may then merge with the basinward edge of the ridge. A gravity low is situated between Marvin Spur and the Lomonosov Ridge. Further south, toward Siberia, the en echelon ridges making up the Lomonosov Ridge trend obliquely into the Amerasian Basin and die out basinward. This structure is interpreted as defining a complex sheared margin that is compatible with the rotational model for the development of the Amerasian Basin. This model predicts a pure shear margin at the Greenland end of the Lomonosov Ridge with motion becoming more oblique to the trend of the Lomonosov Ridge toward Siberia. We suggest that Marvin Spur marks the ocean-continent boundary in the shear portion of the margin and that the oblique ridges and basins at the Siberian end or the ridge consist of extended continental crust affected by trans-tensional rifting.

T12B MCC: Level 1 Monday 1330h

Drilling at the Hawaii-2 Observatory and the Nuuanu Landslide Posters

(joint with B, S, V)

Presiding: **R A Stephen,** Woods Hole Oceanographic Institution**; J Kasahara,** Earthquake Research Institute, University of Tokyo

T12B-0451 1330h INVITED POSTER

Petrogenesis of the Crystal Vitric Tuffs recovered 300 km Northeast of Oahu, from ODP Leg 200: Pyroclastic or Landslide Deposit?

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Hawaiian volcanoes frequently experience flank failure that generate landslides, debris flows, and turbidity currents. The largest landslide known to have occurred on the Hawaiian islands is the Nuuanu landslide. The Nuuanu landslide resulted from the collapse of Koolau volcano on the island of Oahu, Hawaii approximately 2 million years ago where 40% of the Koolau volcano was removed. An ancillary objective of ODP Leg 200 was to