rely solely on recent arching of the range, but rather suggest that the Apennines have long existed as an eastward-migrating arch with a landscape close to or in geomorphic steady-state. The geomorphic steady-state condition is expressed by the mouths of Adriatic-Po flank streams that are elongating as the thrust front propagates eastward at the same rate that their headwaters are being pirated away by the Tyrrhenian flank drainages. From a frame of reference outside the Apennines, the rate of eastward divide migration is matched by the rates of eastward elongation of Adriatic-Po flank river mouths and eastward consumption of Tyrrhenian flank river mouths by subsidence. The result is a topographic "standing-wave". Our ongoing investigations are dedicated to documenting these steady-state geomorphic processes and whether they have resulted in a steady-state Apennine topography, or if the topographic standing wave has recently changed in both width and amplitude.

T51F-09 1050h

Geomorphological Evidence Bearing on the Paired Compressional-Extensional Fronts of the Northern Apennines

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The close association of compressional folding and extensional normal faulting in the Northern Apennines has long attracted the attention of geologists. Elter et al.(1) showed that an extensional front has been following along, about 100 km behind a NE-migrating compressional front. This puzzling tectonic pattern has most commonly been explained by delamination and rollback, but the identity of the delaminating unit has been controversial.

Little attention has been paid to the question whether the migration of the paired tectonic fronts and the generation of structures has been episodic or steady state. Since most or all of the Northern Apennines has emerged from the sea in Neogene time, the drainage pattern of the Peninsula may provide evidence bearing on this question. At the latitude of Gubbio, many short, straight, parallel rivers flow northeast from the main drainage divide to the Adriatic Sea, cutting through large anticlines between the extensional and compressional fronts. Alvarez (2) showed that this pattern arose from a process suggested by Mazzanti and Trevisan (3), in which incipient anticlines, additions to the coastal plain, and downstream increments of the rivers formed synchronously at the advancing shoreline. Deeper and deeper gorges cutting higher and higher anticlines southwest from the Adriatic coast show that the eastern third of the Northern Apennines formed in a roughly steady-state process.

From the Tyrrhenian coast to the drainage divide, grabens that formed behind the extensional front have produced a trellis pattern in the three master streams (Arno, Ombrone, Tiber). In the steady-state hypothesis, many short, straight, parallel streams the former headwaters of the Adriatic rivers would have been disrupted by graben formation and progressively (from SW to NE) added to the trellis pattern. Close to the extensional front, this disruption would have occurred only in Quaternary time, and one would predict that the abandoned headwater tracts would be recognizable. A few candidates are currently under investigation, but the predicted patterns are difficult to detect, and there is little to suggest that the present drainage divide has migrated. This suggests that the steady-state migration of topographic features does not extend back beyond Late Miocene or Early Pliocene time. This is supported by the fact that the Monte Nerone-Monte Catria anticline, forming the main Umbria-Marche Ridge, about 15 km east of Gubbio, is far more structurally elevated than any feature for 100 km to the west.

Departure from steady-state topographic evolution may have been driven at the surface by km-scale sea level drawdown during the Messinian salinity crisis or by 100-m-scale Quaternary sea-level oscillations. Or the driver may have been at depth, e.g., duplexing or out-of-sequence thrusting, or episodic delamination. On the other hand, the model of migrating paired fronts, which has guided Apennine research for 25 years, might be in need of major revision.

(1) Boll. Geofis. Teor. Appl. 17, p. 3, 1975. (2) Basin Res. 11, p. 267, 1999. (3) Geog. Fis. Din. Quat. 1, p. 55, 1978.

T51F-10 1105h

Geodetic Deformation in the Central-Southern Apennines (Italy) From Repeated GPS Surveys

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We analyzed the horizontal strain rate field of a sector of the Central-Southern Apennines. This area was a site of large earthquakes in the past, and its present low seismicity could suggest a high seismic hazard. The number of permanent GPS stations is still too limited to provide a satisfactory description of the highly heterogeneous strain field which seems to affect this zone; thus, the use of non continuous but denser GPS networks is still a fundamental tool. We used GPS data collected during yearly repeated campaigns performed from 1994 to 2001 on the GEOMODAP network. Site velocities were obtained starting from the daily coordinates and covariance solutions, using a Kalman filter approach. We used the ITRF2000 solution for European IGS stations to compute an Euler pole and to determine a stable Europe reference frame. The residual velocity field obtained shows two different prevalent motion trends, NNE-ward for the eastern sector of the network and NW-ward for most of the sites of the western side. The mean strain rate tensor obtained from a least square inversion method, over a sub-network oriented approximately SW-NE, shows a significant extensional deformation (1.5x10-8 strain/yr) about normal to the Apennine chain, in agreement with seismological and neotectonic data. On the basis of a network dimension of about 250 Km, this value gives a well constrained estimate of the extensional velocity of about 4.0 mm/yr, normal to the chain axis, that can be considered an upper bound of the active extensio of this area. In order to detect changes in the spatial pattern of the strain rate field within this sub-network we used a least square inversion method that interpolates the velocity solution and solves for the velocity gradient tensor over a regular grid. This analysis shows a more complex picture, with a transition of the strain rate field from about N-S compression in the Tyrrhenian side to about NE-SW extension toward the Adriatic.

T51F-11 1120h

Active Microplate Deformation and Crustal Delamination in the Southern Circum-Tyrrhenian region, Italy: GPS Velocities from the Peri-Tyrrhenian Geodetic Array

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A GPS velocity field for 30 sites of the Peri-Tyrrhenian Geodetic Array distributed around the southern Tyrrhenian basin indicates differential motion between Sardinia, Sicily, and southern Italy. The GPS sites are located in bedrock and were occupied in 1995, 1997, and 2000 for 18 to 24 hours during each campaign. The GPS data were processed with BERNESE (4.2) in the ITRF97 realization using the continuous GPS sites at Matera (MATE) in southern Italy, Noto (NOTO) in Sicily, and Cagliari (CAGL) in Sardinia for fiducial reference. In a reference frame fixed on Sardinia, which has a velocity consistent with Eurasia, both Sicily and southern Italy show N to NW motion of 5-10 mm/yr. Differential NW-SE convergence of 5-8 mm/yr between Sardinia and Sicily is consistent with thrust earthquake focal-mechanisms along the southern Tyrrhenian margin. In a southern Italy fixed reference frame, shortening in the Apulian foreland is accompanied by NE-SW extension at 6-8 mm/yr along the Tyrrhenian margin, consistent with contractional and extensional earthquake focal-mechanisms. In a fixed Sicily reference frame, southern Italy moves S to SE at 4-6 mm/yr. NE-SW extension along the eastern margin of the Tyrrhenian Sea is accompanied by net N-S shortening across the basin. Sicily and southern Italy have velocities inconsistent both with Eurasia and Africa suggesting active displacement of the Adriatic microplate. Differential motion between Sicily and southern Italy indicate non-rigid behavior and internal deformation within Adria. The SE-directed late Miocene to recent migration of active oceanic seafloor formation in the southern Tyrrhenian basin may reflect propagation of crustal flexure and crustal delamination driven by N-S shortening.

T51F-12 1135h INVITED

Seismic structure of the Adriatic Lithosphere.

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We use data collected by the 1994 Northern Apennines Transect to investigate the structure of the lithosphere beneath the eastern coast of Central Italy. We reprocessed records of teleseismic P waves obtained at station NAP9 (Monte Conero, near the Adriatic coast) with a multitaper spectral correlation (MTC) receiver function estimator. This station lies above the Adriatic lithosphere, in the foredeep of the Apennines convergent margin. We computed both radial and transverse receiver functions (RFs).

Use of the MTC algorithm allows us to examine data from a broad range of directions and distances. Best sampling in backazimuth is obtained in the northeastern quadrant (0° - 110°), where sources span a range of epicentral distances between 30° and 150°. Examination of the wavefield evolution with backazimuth and epicentral distance helps us identify converted-mode phases that are associated with the seismic structure of the lithosphere. We also explore the frequency dependence of the wavefield to assess the length scales of seismic structures associated with specific phases in RFs.

P-S converted phases observed in broad backazimuthal ranges are consistent with the folowing seismic structures within the Adriatic lithosphere: 1) a mid-crustal shear zone at 15-20 km depth; 2) a sharp increase of seismic velocity at ~50 km depth, with considerable anisotropy implied by a well-developed transverse RF phase; 3) a diffuse increase of seismic velocity at ~30 km depth, best seen from the ENE direction; 4) an anisotropic boundary at ~100 km depth not associated with a significant change of isotropic properties.

Both features 2 and 3 are candidates for the crust-mantle transition within the Adriatic lithosphere. Complicated structure and uncertain definition of the Moho have been noted in this region from previous active-source seismic profiles. The transverse converted-phase that defines feature 4 does not switch polarity in the 0° - 100° backazimuthal range. This is consistent with anisotropy-inducing fabric lineation along the strike of the subduction margin in the Adriatic. A similar orientation of mantle fabric was suggested by teleseismic shear-wave birefringence measurements at this site.

T51G MC: 310 Friday 0830h

Nankai Seismogenic Zone: Fluids, Sediments, Experiments, and Fault Rocks *(joint with OS, S)*

Presiding: **J C Moore,** University of California Santa Cruz**; M Underwood,** University of Missouri

T51G-01 0830h INVITED

New Insights on the Fluid Flow Regime in the Nankai Trough Subduction Zone

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The Nankai Trough accretionary prism is formed by subduction of the ~15 Ma Philippine sea plate beneath the SW Japan arc at 4 cm/yr, and by active sediment accretion. The Nankai Trough has generated earthquakes of larger than magnitude 8, the most recent one in 1946. Recent modeling found the up-dip limit of the seismogenic zone to coincide with the ~150C isotherm and the down-dip limit with the 350°-450°C isotherm.

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A more in depth understanding of the relations between overpressure, fluid generation or consumption, phase transformation, and seismicity has been the key focus of recent subduction zones research. Modeling of the pore fluid chemical profiles of the three Sites along the Muroto transect, which were drilled during ODP Legs 131 and 190, provide new insights on the hydrologic regime at this subduction zone.

Site 1173, the pre-deformation reference site, is situated 10.5km seaward of the deformation front; Site 1174 is 1.8 km arcward, and Site 808 is 3.4 km arcward. The most pronounced feature of the pore fluid chloride transect, is the ∼350m broad low-Cl zone situated in the lower Shikoku basin unit at all three sites. A long generally linear profile connects this low-Cl zone with the sediments overlying the Upper Shikoku Basin facies at Sites 808 and 1174. At Site 1173, this linear section is not as well developed. The extent of Cl dilution relative to seawater concentration evolves from 20-21% at Site 808, to 16-17% at the intermediate Site 1174, and 8-9% at Site 1173. In general, the profiles are increasingly smooth going seaward from Site 808 to Site 1173.

The outstanding feature in the Cl isotope profile at 808 is that the values are significantly lighter than that of seawater. In the turbidite section the values range from -3.8 to -6.2 per mil and below 600 ∼bsf between -6.0 to -7.8 per mil. The Cl isotope profile clearly indicates that some of the light Cl isotope ratios likely reflect clay formation, and at > 600m, they likely reflect the uptake of Cl by deep-seated hydrous silicate reactions that occur at > 300°C. Accordingly, the broad low Cl zone most likely carries a mixed signal of dilution via hydrous silicate dehydration reactions and Cl uptake by high temperature reactions.

The combined Cl concentration profiles and isotopic data were modeled for flow paths, flow rates, and timing of episodic flow events. The concentration and isotopic data imply that horizontal advection dominates the vertical Cl profile and that horizontal flow only along the dcollement does not adequately describe the flow regime. The Cl profile from Site 1174 clearly shows that the dcollement is not presently a conduit of low-Cl fluids, however, it may have been a conduit in the past as suggested by the isotopic data. The broad low-Cl region is the result of previous injections of low-Cl fluid that have subsequently dispersed while the local minima are controlled by recent flow. We estimate that presently the flow conduits compose ∼ 30 to 50 % of the section below the dcollement. This gives a depth averaged flow rate transport for this region of 1.0-2.0 cmyr. The ratio of the integrated transport to the subducted transports provides estimates for the relative periods of episodic flow events that are frequent.

New data that would be provided by deep drilling at the Nankai Trough subduction zone will better constrain our model calculations on the fluid flow regime, thus, on the physical-chemical conditions at the seismogenic zone.

T51G-02 0845h

Smectite and Fluid Budget at Nankai ODP Sites Derived from Cation Exchange Capacity

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The source of the low-Cl fluids at the toe of the Nankai accretionary wedge is debated. Low-Cl fluids are thought to originate from smectite to illite transformation at the updip limit of the seismogenic zone. Low-Cl at the deformation front drill sites was interpreted as evidence for fluid flow along the decollement. However, the temperature range at these drill sites is within the smectite to illite transition and the low-Cl fluid source may thus be local. Cation exchange capacity (CEC) is here used as a proxy for smectite content and Cl-free (bound) water content in the bulk sediment. Analysis of soluble chloride and residual water content in samples squeezed for pore water extraction yields Cl-free water content of about 12 H_20 per exchangeable cation. This ratio is typical of smectite in the 2-water-layer state. CEC data were obtained on samples from Leg 196 Sites 1177, 1173 and 1174, and Leg 190 Site 808. Evolution of CEC between Sites reflects smectite crystallization during ash alteration as well as smectite to illite transformation at a higher temperature. If Site 1177 is taken as a reference, decreased CEC in the Lower Shikoku Basin facies at Site 1174 corresponds to conversion of 15% bulk sediment weight from smectite to illite, enough to cause the observed freshening. In the Upper Shikoku Basin facies, CEC stays constant or increases. This suggests the sediment goes through a maximum of CEC and smectite content during diagenesis. Compaction occurs at the same time and pore fluid migrates upward in the sedimentary column. We apply a 1-D model of compaction and diagenesis to the evolution of pore fluid chlorinity with time. Preliminary models of pore fluid evolution between 1173 and 1174 suggest that the shape of the chlorinity profile could be explained if ash alteration in the Upper Shikoku Basin facies caused a temporary increase of smectite content. We do not claim that there is no fluid flow along the decollement but are very cautious about using the shape of the chlorinity profile as a supporting argument. Site 808 data will be available this fall and will provide additional constraints.

T51G-03 0900h

Sedimentary Inputs into the Nankai Seismogenic Zone

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Seismic reflection profiles and drilling results from DSDP/ODP Legs 31, 131 and 190 show that the subducting strata and thermal regime of Shikoku Basin change considerably in three dimensions. Characterization of this 3-D variability is an important component of SEIZE-related research in Nankai Trough. The fossil spreading ridge and Kinan Seamounts of central Shikoku Basin control changes in heat flow and sedimentary facies within the subducting strata. The Ashizuri transect (Sites 297 and 1177) is located west of the ridge in a region of low heat flow and subdued basement relief. Early Miocene to early Pliocene strata there include abundant siliciclastic turbidites, and smectite content is typically 25-55 percent of the bulk mudstone. Ring-shear tests show that increases in smectite content cause substantial reductions in the rock's coefficient of internal friction, but the relation is complicated because of secondary effects of volcanic ash, illite, and chlorite. Progressive transformation of smectite to illite (S-I) along the Ashizuri plate boundary should affect both its down-dip frictional strength and fluid budget. Release of interlayer water from subducting smectite-rich strata creates a stronger potential for excess pore-fluid pressure.

In contrast to Ashizuri, the Muroto transect (Sites 808, 1173, 1174) is located on the fossil ridge axis where heat flow is high (180 mW/m2, or higher) and basement relief is rugged. Miocene-Pliocene turbidites do not exist above the basement highs, and smectite-to-illite diagenesis progresses to an advanced stage even before Shikoku Basin strata are buried beneath the Nankai trench wedge. Early loss of interlayer water affects pore-water chemistry seaward of the subduction front, but it also limits potential down-dip effects of clay diagenesis on pore pressure. Kinetic models of early clay mineral diagenesis match our documented profile of I/S mixed-layer clays. On the other hand, the S-I reaction creates a dilemma for mass-balance calculations because the so-called reference site (1173) is heavily altered. We believe that smectite values within the Ashizuri transect (25-55 percent of bulk sample) represent initial conditions within the Muroto transect area. In addition, differences in reaction progress along strike should lead to unequal changes in frictional properties and/or effective stress down the decollement, with the Muroto corridor affected less than Ashizuri.

T51G-04 0915h

Frictional Coefficients of Multi-Component Sediments: Implications for the Aseismic to Seismic Transition Zone, W. Nankai

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The effect that diagenesis and mineralogical changes have the frictional properties of subduction thrusts during progressive burial and heating is uncertain. The reaction of S to I has been put forward as being one potential factor in controlling the depth of aseismic/seismic transition zone. Presented are the initial results from ring-shear and direct-shear studies of the complex interrelationships between multi-component mineralogies and residual friction coefficients (RFC) at effective normal stress of between 0.1 MPa and 30MPa. Both saturated natural Nankai margin samples (DSDP Site 297) and pure mineral mixtures were tested. Preliminary XRD results indicate that the incoming W. Nankai Ashizuri transect becomes increasingly dominated by smectite (S) at depth (up to 40-50% bulk sediment), contrary to the expected depth trends based on the S to illite + chlorite (I + Ch) reaction. Partly as a result of this, a significant number of the W. Nankai samples have low RFC values (0.13-0.2), suggesting that even in the absence of elevated fluid pressures the basal decollement should be very weak at aseismic depths. Observed is the expected strong positive correlation between RFC values and Qtz. + Plag. (granular) volumetric ratio. An increase from 0.2 to 0.8 in volumetric ratio corresponds to an increase in RFC from 0.13 to 0.53. Significantly, however, the RFC values of the multi-component Nankai samples predominantly fall on trends similar to those determined for mixtures of pure Qtz. and S. No strong contrast is developed between samples with varying proportions of S, I, and Ch in the clay fraction. This suggests that RFC values for the I and Ch clays in the natural Nankai samples probably lie relatively close to that of S (i.e. somewhere <0.3). In addition, direct shear studies reveal that the RFC of saturated Qtz and S mineral mixtures progressively decrease (-0.004 MPa-1) as effective normal stresses increase. Overall, the results of the initial studies indicate the aseismic portion of the subduction system is weak, and that there should be no expectation that RFC increases significantly with depth for purely mineralogical reasons even as the S to I reaction proceeds, particularly if effective normal stresses rise.

T51G-05 0930h

Velocity and Porosity of Nankai Trough Sediments: Effects of Deposition, Diagenesis, and Deformation

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Central objectives of the recent two-leg Nankai Trough drilling effort included characterization of the initial state of Shikoku Basin sediments prior to accretion, and the evolution of those sediments and their pore fluids during initial accretion, underthrusting, and decollement formation. Key elements of this characterization are porosity and seismic velocity, and their relationship to one another and to effective stress. Because most of the margin is sampled only by seismic data, velocity-porosity conversions are a potentially powerful tool to address margin evolution, stress state, and solid and fluid component mass balances. Beyond seismic calibration, velocity and density data can shed light on intrinsic sediment texture (depositional, diagenetic, and deformational) and mechanical properties through the application of petrophysical models. Toward these ends, various combinations of log- and core-based Vp, Vs, and density/porosity data have been collected at Sites 1173, 1174, and 808 at multiple frequency scales.

In previous work at Nankai and other margins, seismic velocity structure has generally been converted to porosity and/or excess fluid pressure by implicitly assuming a compaction equilibrium model (i.e., fitting the velocity-porosity transform with a function typical of normal burial compaction). Velocity and density data from the Shikoku Basin reference site show substantial excursions from a burial compaction model even seaward of all margin-related deformation. Porosity, Vs and Vp data here are interpreted as controlled by early grain contact cementation, and subsequent temperature-dependent silica diagenesis at depths greater than 400 m below sea floor. Deeply buried portions of the more landward Sites 1174 and 808, including the underthrust sections, exhibit arrested consolidation patterns, as well as deviations from compaction-disequilibrium trends, especially near the decollement. Implications of the derived velocity-porosity relations for interpretation of fluid content and stress based on seismic reflection data will be explored.

T51G-06 0945h

Laboratory Results Indicating Intrinsically Stable Frictional Behavior of Illite Clay

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Along plate boundary subduction thrusts, one of the key mineralogical changes thought to affect frictional behavior is the transformation of smectite to illite at temperatures $> \sim 150^{\circ}$ C. This hypothesis is based on (1) limited laboratory observations showing that smectite exhibits velocity-strengthening behavior (frictional strength increases with slip velocity), which produces only stable slip, (2) previous work showing stick-slip behavior of heated illite gouge under some conditions and over limited displacements, and (3) the results of thermal models indicating an apparent correlation between the location of the modeled 150° C isotherm and the observed updip limit of seismicity at some subduction zones. At the Nankai subduction zone, the incoming sediments of the Shikoku basin are clay-rich, but also contain significant amounts of quartz and plagioclase.

We report on laboratory experiments designed to investigate the frictional behavior of smectite-illite clays and their possible role in determining frictional stability in subduction zones. We crushed and sheared 5 mm-thick layers of commercially obtained illite shale (grain size $< 500\ \mu m$) in the double-direct shear geometry to displacements of 20-28 mm (shear strains of 6-8) at room humidity and temperature. XRD analyses show that the shale contains dominantly clay minerals and quartz. Within the clay-sized fraction, $< 2\ \mu m$ the dominant mineral is illite. Thus, we consider this shale as an appropriate analog for fine-grained sediments incoming to subduction zones, within which smectite has been transformed to illite.

We find that illite gouge has a coefficient of sliding friction (μ) of 0.42-0.68, consistent with previous work. Over a range of normal stresses from 5-150 MPa and sliding velocities from 0.1-200 $\mu m/s$, we find only velocity-strengthening behavior, opposite to the widely expected, potentially unstable behavior of illite. Our previous work shows that smectite sheared under identical conditions exhibits low friction (μ = 0.15-0.32) and a transition from velocity weakening at low normal stress to velocity strengthening at higher normal stress (>25 MPa). If our results can be extended to natural faults, they suggest that the transformation of smectite to illite results in an increase in friction, but does not cause a change to velocity-weakening behavior. We need to expand the range of conditions studied, including higher temperatures and more complex fluid conditions; however our initial results do not support the hypothesis that the smectite-illite transition is responsible for the seismic-aseismic transition in subduction zones. We suggest that other diagenetic processes, such as quartz cementation, consolidation, and lithification, may play an important role in changing the frictional properties of subduction zone faults, and that these processes, in addition to clay mineralogy, should be investigated in future studies.

T51G-07 1020h

Towards the Understanding of Earthquake Generation in Accreting Subduction Zone: A summary of ODP Leg 196 Activity at the Nankai Subduction Zone.

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Leg 196 was scheduled as a latter half of a two-leg drilling program, ODP legs 190 and 196, at the Nankai Trough where cyclic recurrence of gigantic earthquakes has been conceived in the history. Although it is now well recognized that earthquakes at the Nankai Trough are generated by relative rapid movement of one plate against the other at the plate boundary which can be well described by coseismic tsunami generation mechanisms, observations limited to the Earthfs surface has constrained us to get more detailed knowledge about real stress accumulation processes, role of fluid, earthquake triggering mechanisms, control on recurrence periodicity, etc., which comes on top of the faulting mechanism due to subduction. A joint effort has begun to understand environmental conditions surrounding the Nankai Trough at the time of ODP leg 131, and a great amount of better knowledge about the accretionary tectonics at Nankai has been stacked in the former legs. Leg 196 was conducted to enhance the results of previous legs using LWD and long term monitoring techniques at two locations, Sites 808 and 1173. During the leg 196, log physical properties, such as porosity, density, etc., around the decollement and the long-term monitoring systems were acquired and will provide data to reveal the role of fluids beneath the seafloor to contribute to further seismogenic studies in terms of geophysical conditions. We think this work is a first step in a long term research process to ultimately drill into the earthquake-producing zone under the Integrated Ocean Drilling Program using the new drillship being constructed in Japan. This future drilling will provide us insights for the seismogenic processes at the Nankai Trough based on the physical evidence on hypotheses brought by the drilling in the legs 131-196.

T51G-08 1035h

Deformation and In-situ Stress Observations in the Nankai Accretionary Wedge: Results from ODP Leg 196 Logging-While-Drilling (LWD) Resistivity Imaging

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360° borehole resistivity images at Leg 196 (Nankai prism) were used to assess deformation. Deformation was indicative of basinal compaction at the reference site 1173 and concentrated in discrete zones at Site 808 (toe of wedge), including the frontal thrust and the décollement. Fractures in the upper part of the accretionary wedge were steeply dipping ($>30^{\circ}$) with average orientation WSW-ENE, in agreement but slightly deviating from 90° to the convergence vector (310-315°). The décollement shows minimal deformation compared to prism fault zones and the dominant fracture and bedding strike is closer to N-S. Fractures in the lower half of the borehole show no preferred orientation. All deformation zones (except the décollement) were characterized by high resistivity (porosity collapse?) with conductive (open?) fractures. Drilling induced borehole breakouts throughout much of Hole 808. Strong breakouts coincided with a trench-fill facies unit, suggesting reduced sediment strength. Breakouts indicate minimum horizontal stress orientations(σ_2) of N40-50°E throughout the borehole, compatible with the convergence vector (σ_1) but deviating slightly from the average fracture orientation. Preliminary analysis suggests bounds can be placed on in situ horizontal differential stress magnitude, based on imaged breakout dimensions. Stress quantification will require cohesion and shear strength data from mechanical testing of core samples. Deformation within the toe of the Nankai accretionary wedge is consistent with measured convergence, but deviations with depth in the borehole and between breakouts and fracture orientations may suggest the effects of inherited structures, temporal variability in stress orientation or isolation from convergence.

T51G-09 1050h

Compactive and Dilative Deformation and Fluid Pressure Cycling: Evidence from Log-Core Integration, ODP Leg 196, Nankai Subduction Zone

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Site 808 penetrates both the frontal thrust zone and decollement zone at the toe of the Nankai subduction zone. Because hole enlargement degraded some of the density data, we selected maximum rotational density from intervals with hole radius less than 0.7 inch larger than the tool and collected less than 1.5 hours after cutting the hole. These data agree with core measurements outside fault zones and are considered reliable. In the frontal thrust zone, the density data show a clear increase through a thickness of about 20m, suggesting compactive deformation. Resistivity is also sharply higher over this interval suggesting higher density. LWD density, selected as above, begins to decrease about 40m above the base of the decollement zone. Resistivity also shows a decrease over a similar interval, supporting the trend indicated by LWD density. In contrast, density measurements from core samples continue to increase downward in the decollement zone. The decreasing density/resistivity trend in logs is apparently due to the increased amount of fluid-filled, unhealed fractures and a bulk porosity increase. Therefore, a combination of log and core measurements suggests that the decollement zone is an interval of enhanced porosity, probably fracture porosity, encompassing blocks of sediment of relatively higher density (indicated by small-scale core measurements). Expanding the observed core density to that of LWD density requires 9 percent dilation of core material (less if mean core density is lower due to selective sampling). This fracture porosity is presumably dilated by high fluid pressure, in contrast to the frontal thrust that is densified and not as highly overpressured. The densified core samples of the decollement zone suggest an earlier history of compactive deformation, presumably associated with lower fluid pressure. Thus, log and core density measurements suggest fluid pressure cycling in the decollement zone.

T51G-10 1105h

Porosity in the Nankai Accretionary Wedge Décollement as Inferred from LWD Resistivity Measurement During ODP Leg 196

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During May-June 2001, Ocean Drilling Program Leg 196 investigated the relationship between deformation, physical properties and fluid flow in the accretionary prism of the Nankai trough zone. The first part of this Leg focused on Logging While Drilling (LWD) at Site 808 at the deformation front cored during Leg 131 and Reference Site 1173 about 12 km seaward cored during Leg 190. A major objective of the Leg was to determine in-situ porosity in the wedge frontal thrust and décollement. Bulk density, electrical resistivity and acoustic wave velocity were measured by LWD. We focus on the interpretation of resistivity. Sediment nature requires taking into account surface conductivity and its variation with temperature as well as sediment anisotropy. We use a variation of the dual-water model to derive matrix porosity from resistivity. Parameters are adjusted using porosity derived from the density log in selected intervals at both sites with good hole conditions and away from fault zones. We show that in the fault zones, the effect of fracture porosity on conductivity must be taken into account and we estimate fracture porosity and conductivity from log data and measurements on samples. Overall the frontal thrust appears as a resistive, and compactive, structure whereas the décollement appears as a conductive, and dilatant, one. However, high resolution analysis and comparison with porosity measured on samples suggest that dilatant and compactive behavior occur in both shear zones.

T51G-11 1120h

Exposed fossil seismogenic faults within the accretionary complex -Analogue to the Nankai Seismogenic zone-

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Ancient accretionary complexes exposed on land might have suffered from seismic process in the subduction zone and presents an analogue to geology of the Nankai Seismogenic zone. We investigated the Shimanto Accretionary Complex in SW Japan and found several seismogenic fault candidates during the underthrusting of the complex.
The most clear geologic evidence of seismicity is the recognition of psuedotacylyte originated from frictional melting and was firstly reported from the Shimanto accretionary complex in SW Japan (Ikesawa et al., 2000, Sakaguchi et al., 2000). The pseudotachylite is located along a fault between different lithological units; underplated melange and offscraped coherent units. Such geologic setting of the fault is analogous to seismogenic decollement in modern subduction zone. Detailed P-T analysis of host rocks (about 250°C, 200MPa) and the pseudotachylite (about 700°C) by using mineral assemblange and fluid inclusion within mineral veins suggests the setting.
Second candidate for the seismogenic fault rock; ultracataclasite is commonly observed within melange. The fault shows a straight brittle fault with a few milimeters thick cataclastic vein. The faults systematically displace the melange for a few meters. Fabric relationship of the fault with melange is systematic and suggests a brittle breakage in the last stage of ductile shear of melange. Pressure solution creep of melange and the cataclastic breakage appear to be inter- and co-seismic deformation in the subduction zone, respectively.
Third seismogenic rock is cataclastic basalt block encircled by melange. The cataclastic basalt suggests a brittle breakage of oceanic crust and involvement into the tectonic melange of accretionary complex. Extremely sharp and thin fault veins of untracataclasites surrounded by less deformed cataclastic basalts are commonly observed within basalt blocks. Such occurrence suggests seismic event associated with asperity breakage of the oceanic basement.

T51G-12 1135h

In-situ pressure - temperature condition of tectonic melange : constraints from fluid inclusion analysis of syn-melange veins-

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One of the most reliable settings for the tectonic melange with composite planar fabric is along the decollement in the subduction zone (e.g. Cowan, 1985; Moore and Byrne, 1987; Kimura and Mukai, 1991). The decollement is developed from aseismic shallow part to seismogenic zone of several to tens of kilometer in depth. The decollement-related-melange, now exposed on land, might therefore record the deformation process along the aseismic to seismogenic decollement.
Trapped pressure and temperature of fluid inclusion is estimated from "syn-melange" veins developed around the necks of boudin of sandstone blocks in the melange of the Shimanto Belt, SW Japan. The melange was decollement-related tectonic melange. Fluid inclusion analysis from "syn-melange" veins might be only tool to reveal the P-T condition during melange formation. The result of P-T estimation ranges from about 150(25)°Cto 220(31)°C for temperature and from 81 (+15) MPa to 235 (18) MPa for pressure. Geothermal gradient estimated from the result is between about $10.0(+0.2/-1.5)$°C/km (lithostatic) and $4.2(+0.1/-0.9)$°C/km (hydrostatic) if the fluid pressure ratio to lithostatic pressure is constant in each datum.
The estimated lithostatic thermal gradient is much closer to that calculated from the oldness of the subducting oceanic plate. P-T range suggests that melange was formed enough within the seismogenic zone hypothesized by thermal model although the deformation mechanisms of melange, dominant diffusive mass transfer with minor brittle breakage, do not show the seismic deformation. One possible explanation for this discrepancy is that the melange was formed during the interseismic period. Alternative explanation is that melange formation was accomplished before subducting into the seismogenic zone but around the seismic front. Lithification front hypothesis for the seismic front suggests such frontal setting for the melange.

T52A MC: Hall D Friday 1330h

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

Presiding: **F Martinez,** University of Hawaii**; P Huchon,** Observatoire ocanologique de Villefranche

T52A-0904 1330h POSTER

A MODEL OF THE KINEMATICS OF THE DANAKIL MICROPLATE

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We present a regional approach to the tectonics of the Afar depression, in which we attempt to relate reconnaissance-scale data to overall movement of a Danakil microplate. Topographic, satellite, airphoto, magnetic and gravity data from the flanks and interior of the Afar depression, NE Africa, are used to assess differing models of the dispersal of the Danakil microplate from its western to its eastern margin. The data are compared to small circles about published instantaneous poles to find evidence of strike-slip and transverse features. A good fit to such features is made using a statistically-significant modern pole to the NNE of the Afar depression. A possible reconstruction about this pole, which reunites branches of an inherited shear zone, is presented. This reconstruction is not consistent with a 'crank-arm' or 'saloon-doors' mode of opening for the Afar depression. Instead we suggest that only recently has the Danakil microplate come into existence, after the westwards propagation of the Gulf of Aden rift into the Afar depression. Prior to this time movement of Danakil occurred very slowly about the same pole, but as part of the Somalian plate; as shown by the continuity of ancient flowline features onto the Nubian margin of the Main Ethiopian Rift. At 7 Ma, possibly due to the onset of oceanic-type accretion in Afar where the lithosphere was hot and thin already from the presence of a hotspot, Danakil accelerated eastwards about this pole. In response the Gulf of Aden rift propagated westwards to form a new plate boundary between Danakil and Somalia. The newly-formed Danakil microplate is thus an intermediate stage in the transfer of all or part of the Danakil horst to the Arabian plate from the Somalian plate. Further south, at the Main Ethiopian Rift, continental lithosphere did not rupture but the presence of focussed accretion at Afar in a hitherto-diffuse plate boundary precipitated the southward migration of the SomaliaNubia pole to its present-day position. This event coincides with a change in volcanic style at the Main Ethiopian Rift.

T52A-0905 1330h POSTER

Mechanisms of Continental Extension and Africa-Arabia separation: Constraints from Laboratory Experiments

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We study the mechanisms of continental extension and rifting through the example of Africa-Arabia separation. The influence of the Zagros-Makran subduction and of the Afar hot-spot on the geometry and kinematics of rifting in the Aden-Red Sea region are investigated through laboratory experiments. Our goal was to unravel the effect of the dynamics of the subduction on the deformation of the subducted (Arabic) plate.

We used a three-layer analogue model where sand and silicone represent respectively the brittle and ductile lithosphere, and where honey represents the viscous upper mantle. The negative buoyancy of the sand/silicone unit is the main driving force for subduction, while the bending resisting force of the sand/silicone unit tends to slow down subduction. Preliminary models were realized to characterize the effect of the boundary conditions and the effect of an additional circular weakness corresponding to the Afar hot spot. In more complex models, we simulate the deformation of Northeast Africa during the Tethyan lithosphere subduction and Zagros collision simultaneously with the activity of the Afar hot spot.

These models contribute to explain the presence of distributed extensional deformation in northeast Africa before rifting and the final Africa-Arabia separation. They explain the timing of these extensional events. Subduction has been active since the Mesozoic and provides forces which lead to extension within the subducting plate. The Eurasia-Africa collision changes the boundary conditions and triggers the localization of rifting 30-35 Ma ago. These models also explain the location and the geometry of the rifting in the Gulf of Aden and in the Red Sea. The Afar hot spot localizes extension acting as a lithospheric weakness and constrains the rift geometry. The obliquity between the rift direction and the direction of extension explains the internal fault geometry.

T52A-0906 1330h POSTER

Along-axis steps in Ethiopian rift Bouguer gravity anomalies: Implications for crustal thinning and melt emplacement prior to breakup

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The southern Afar depression, Africa, is virtually the only area worldwide where the transition from continental rifting to seafloor spreading is exposed onshore. During mid-Miocene to Pleistocene time the rift valley was segmented along its length by long normal faults; since Pleistocene time, faulting and magmatism have jumped to a narrow ca. 60 km-long volcanic mound marked by small faults. These magmatic segments are structurally similar to slow-spreading mid-ocean ridges, yet the rift is floored by continental crust. As part of the Ethiopia Afar Geoscientific Lithospheric Experiment (EAGLE), we examine new and existing Bouguer gravity anomaly data from the rift to study the modification of the lithosphere by extensional and magmatic processes. New and existing Bouguer gravity anomaly data also show an along-axis segmentation of elongate relative positive anomalies that coincide with the magmatic segments. These anomalies are superposed on a regionally eastward increasing field as one approaches true seafloor spreading in the Gulf of Aden, and crustal thickness decreases. Quite remarkably, the magmatic segment boundaries, where data coverage is good, are marked by 15-25 mGal steps. The amplitude of the along-axis steps, as well as their across-axis characteristics, indicate that magmatic intrusion and ca. 2 km relief at the crust-mantle interface contribute to the steps. We use inverse and forward models of gravity data constrained by existing seismic and petrological data to evaluate models for the along-axis steps. EAGLE seismic data will be acquired across and along the magmatic segments to improve our understanding of breakup processes.

T52A-0907 1330h POSTER

EAGLE Design of 2003 Controlled Source Seismic Profile Across the Ethiopian Rift

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