conjugate Newfoundland and the > 1 km deeper Iberia abyssal margin.

T42C-0951 1330h POSTER

Post-Glacial Eruptive History of the Western Volcanic Zone, Iceland

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We have mapped and extensively sampled all the post-glacial eruptive sequences along approximately 170 km of the Western Volcanic Zone (WVZ) of Iceland. New ^{14}C charcoal ages and tephrachronology constrain the timing of eruptive activity. During post-glacial time (last ∼12,000 yrs) the WVZ has erupted at least 42 times. There is no apparent systematic relationship between eruption location and age, but both eruption frequency and total erupted volume have decreased with time. At least 25 eruptions (58%) are older than ∼9000 yrs. In the last 4500 years the WVZ has erupted only five times, the last time in 1000 A.D. Eruptive activity along the WVZ occurred as two types: (1) Only seven units were clearly produced by fissure eruptions; (2) At least 32 units (>80%) are monogenetic, central vent eruptions, comprising both low effusion rate pahoehoe lava shields (21 units), and tephra cones dominated by aa to transitional lava flows (11 units). The largest erupted volumes are associated with lava shields formed from long-lived eruptions. The total erupted volume of lava in post-glacial time along the WVZ is >90 km^3. Individual eruptions vary from about 0.01 km^3 to more than 15 km^3. Nearly 65% of the total post-glacial erupted volume was produced prior to 9000 yrs ago; about 14% was erupted in the last 4500 years. Chemical evidence suggests that average extent of partial melting may have decreased for at least part of post-glacial time. These results generally support a model of enhanced melt production immediately following glacial unloading, followed by subsequent relaxation. The average volume of individual eruptions for all 42 identified units is about 2.2 km^3, but the median is 0.175 km^3; these values increase to 2.8 and ∼1 when 10 small units of the Grimsnes field on the SE periphery of the WVZ are excluded. There are few good correlations between chemical composition and location within the WVZ, except for incompatible element-enrichment in Grimsnes lavas, restriction of high-MgO picritic shields to the far south, and a tendency for incompatible element depletion to the north. In general, chemical variations within the WVZ are dominated by temporal rather than by spatial variability.

T42C-0952 1330h POSTER

The Iceland Deep Drilling Project (IDDP): Obtaining Supercritical Geothermal Fluid from Hot Spot-Ridge Interaction.

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The Iceland Deep Drilling Project (IDDP) plans to drill one or more boreholes deep enough to penetrate into the supercritical zones believed to be present beneath three currently exploited geothermal systems in oceanic ridge-type spreading centers in Iceland. The main aim is to produce much higher enthalpy fluids for power production than are currently being utilized. The IDDP is being funded by Deep Vision, a consortium of Icelandic energy companies. A feasibility study is currently under-way and is examining three candidate sites as well as the economics and engineering issues of drilling to greater depths and higher temperatures. Responding to the invitation of Deep Vision, a meeting funded by the International Scientific Continental Drilling Program (ICDP), was held in Reykjavik in June 2001, to help define the tasks for the feasibility study and to begin planning a scientific program to take advantage of the IDDP boreholes. A Science Applications Group of Advisors (SAGA) with both Icelandic and international membership has been formed to formulate and oversee these activities. An IDDP-ICDP science workshop on the IDDP will be held in Reykjavik in March 2002 with 50-75 participants to formulate a drilling and science plan. A second workshop is being considered for 2003 and drilling is expected to take place in 2004.

Iceland is a particularly favorable location for research on very high enthalpy geothermal fluids and it is hoped that such fluids can be produced at high flow rates. In Iceland the repeated seismicity and volcanic activity in the rift environments above the hot spot create high permeability and high temperatures at drillable depths. Temperatures greater than 300°C are commonly encountered in wells drilled to depths of 2 km in high-temperature geothermal fields in Iceland. The likely existence of permeable regions in brittle basaltic rock at supercritical temperatures at still greater depths beneath the candidate geothermal fields is inferred from the distribution of hypocentral depths of seismic activity that continues to below about 5 km depth. These circumstances are the product of the special geological environment of Iceland, a coincidence of a mantle plume with the divergent plate boundary at the Mid-Atlantic Ridge. Thus the IDDP offers the international geoscience community a unique opportunity: (a)to investigate the magmatic and fluid circulation character of the Mid-Atlantic Ridge (on land) in relation to the hot spot, and (b)to study and sample fluids at supercritical conditions which resemble black smoker marine hydrothermal systems. These aspects of high-temperature hydrothermal systems have rarely been available for direct observation. International science and engineering participation is welcomed in the (IDDP).

URL: http://www.os.is/IDDP/

T42C-0953 1330h POSTER

Reconciling the Misfit Between the Yellowstone Plume Trace and Global Plate Motion Models: Channelized and Pancake Plume Flow on Basal Lithospheric Topography

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Age-progrssive rhyolitic volcanism from the Owyhee Plateau along the Snake River Plain to the Yellowstone Plateau is widely interpreted as reflecting the motion of the North American plate over a mantle plume. The strongest line of evidence against this interpretation is the misfit between the length of the interpreted plume trace and the length predicted by global plate motion models. As generally represented, the plume trace extends 700 km from the 16.1 Ma McDermitt Caldera to the caldera of the 0.6 Ma Lava Creek Tuff at Yellowstone. Global plate motion models predict a plume trace of 190-340 km in 16 m.y. Extension immediately south of the Snake River Plain has been estimated at 20%, well short of the >100% required to reconcile the misfit. Also complicating the plume interpretation is the position of the feeder dikes of the Columbia River basalts (CRB), widely interpreted as the result of emplacement of the head of the Yellowstone plume, >300 km north of the interpreted plume trace at 16 Ma.

Both of these problems can be reconciled by considering the complex results of interaction of a mantle plume with basal lithospheric topography. The predicted position of the plume at 16 Ma, based on plate motion models plus extension, was near the southern end of the Snake River Plain, under thick Precambrian lithosphere. Thinner lithosphere occurred 150 to 200 km west of this point at the boundary with Paleozoic and Mesozoic accreted terranes. The CRB, Steens Basalts (SB), and Northern Nevada Rift (NNR) basalts were erupted through the accreted terranes west of this boundary beginning about 16.5 Ma. Two processes could link this basaltic volcanism to the plume: (1) assuming the plume head was >600 km in diameter, some plume head material would have risen to shallow depths and undergone decompression melting under CRB and SB dikes and the NNR; and (2) flow of plume head and conduit-fed material up a basal lithospheric gradient from under the cratonic lithosphere toward the accreted terranes would have produced more decompression melts. The latter process is analogous to plume flow toward mid-ocean ridges. Two modes of flow have been evaluated in considering plume-ridge interactions, channelized and pancake flow, with geodynamic models favoring the latter. I suggest that both types of flow occurred in the Yellowstone system in the Miocene. The western Snake River Plain graben connects the projected position of the Yellowstone plume at 17 Ma to the CRB dike swarms. I propose that the development of the western Snake River Plain graben reflects weakening of the lithosphere by channelized sublithospheric plume flow. Further evidence for this process is the observation that CRB lavas became more isotopically evolved over time, consistent with thermomechanical erosion of the Precambrian lithosphere in which the channel was developed. In contrast, the region connecting the projected position of the Yellowstone plume to the SB dikes and the NNR lacks subsequent focussed deformation and is characterized by widespread Miocene caldera systems (including the western 300 km of the canonical plume trace). These characteristics are more consistent with pancake flow. Only after the craton margin was far enough from the plume, at about 10 Ma, did the Yellowstone plume begin to leave a simple plume trace. That channelized plume flow dominated over pancake flow in this setting (CRB volume >3x SB volume) probably reflects greater irregularity in the sublithospheric topography under continents than ocean basins.

T42C-0954 1330h POSTER

Fine-Scale Volcano-Tectonic Patterns Along the Hotspot and Non-Hotspot Influenced Fastest Spreading Parts of the East Pacific Rise, and Their Relation to Hydrothermal Activity

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A broad Easter mantle plume appears to be having a major long-term effect on the evolution of the giant duelling propagator system between the Easter and Juan Fernandez microplates. It is driving long-term propagation of the West ridge of this system toward the south, although there are occasional episodes of duelling propagation of the East ridge towards the north. The West ridge segment nearest the hotspot is the most highly inflated segment and contains several intense hydrothermal vent areas, although the East ridge segment farthest from the hotspot has a higher percentage of axis with active hydrothermal activity. DSL-120 sidescan sonar and bathymetry data collected along the EPR segment axes between the Easter and Juan Fernandez microplates have been compiled into a Quicktime movie. This presentation method provides a fast overview of an immense amount of data, and facilitates comparisons between the hotspot influenced and non-hotspot influenced segments, as well as correlations between the structural data and hydrothermal patterns, with implications for hydrothermal prospecting along mid-ocean ridges. For example, in addition to strong correlations with axial inflation and spreading rate, hydrothermal activity frequently correlates with areas of recent voluminous low-backscatter flows pouring out of axial fissures. Hydrothermal activity shows good correlation with presence of axial summit collapse structures, but not with the presence of an axial summit graben (sensu strictu). Although on a million year timescale the hotspot influence on the West ridge has a dominant effect on the tectonic evolution of this area, on the shorter timescales governing hydrothermal activity the hotspot influence is much less important than individual magmatic inflation events along individual ridge segments.

T42D MC: Hall D Thursday 1330h

Nankai Seismogenic Zone: Thermal Structure, Earthquakes, Seismic Reflection, and Marine Geophysics

(joint with OS, S)

Presiding: **S Gulick,** Univ. Texas**; K Obana,** JAMSTEC

T42D-0955 1330h POSTER

Micro-seismicity off Cape Muroto Along the Nankai Trough Seismogenic Zone Detected by a Series of OBS Observations

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Micro-seismicity observation is a one of the way to monitor a state of stress in the seismogenic zone. We observed micro-seismicity off cape Muroto at the Nankai trough seismogenic zone using pop-up type ocean bottom seismographs (OBS). The recording period of our OBS's are limited to about two months. We repeated installing and retrieving OBS's. A series of OBS observation have been carried out for nine months in total from 1998. In our observation area, a cable-linked OBS system is installed by JAMSTEC. This system has two seismometers. The data recorded by this system was also used in the analysis.

Generally, the seismic velocity structure has a large lateral variation along the subduction zone. We must consider the realistic velocity structure to obtain precise hypocenters. We used 3-D P- and S-wave velocity structure models to locate earthquakes. These models are based on OBS-airgun seismic survey results along the Nankai trough [e.g. Takahashi et al., 1998; Kodaira et al., 2000]. The models represent the characters of the Nankai trough subduction zone, such as subducting seamount off cape Muroto and high Poisson's Ratio in the accretionary prism.

The obtained micro-seismicity seems to be classified into two activities; one is at the plate interface and the other is in the uppermost mantle. Seismicity near the plate interface makes several clusters. Although a seismic-aseismic transition zone has not been clearly observed because of the coverage of our OBS array, these clusters may be caused by the stress concentration as a result of the transition of the plate interface state from unlocked to locked. A partially serpentinized mantle is implied by a low P-wave velocity beneath the subducting seamount [Kodaira et al., 2001]. Along their profile, the upper most mantle seismicity seems to be active at the seaward part of this low velocity mantle. The seismicity in the upper most mantle is probably related to the structure and nature of the down going oceanic mantle.

T42D-0956 1330h POSTER

Deep structures control the source process of the Nankai earthquakes

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Recent seismic surveys in southwest Japan reveal that some characteristic deep structures exist in the earthquake source region of the Nankai trough subduction zone along which great interplate earthquakes have occurred repeatedly. For example, Kodaira et al. [2000] images a subducting seamount in the central part of the source region of the 1946 Nankai earthquake, Park et al. [2000] images some splay faults along the Nankai trough, Park et al. [2001] shows that some strong reflectors exist just above the plate boundary landward of decollement zone, and so on. These deep structures are well correlated to the slip pattern estimated from tsunami wave form by Baba et al.[2001].

To reveal that how such structures control the source process of the Nankai earthquakes, we demonstrate some simulations of dynamic rupture propagation on a plane. The numerical technique is based on a boundary integral equation method in 3D elastic medium [Aochi et al., 2000]. We give a slip-weakening law as a fault constitutive law and assume that the residual stress level is consistent with the stable frictional stress level estimated for the Nankai subduction zone [Wang and Suyehiro, 1999]. The break down stress drop is constant on a fault except at the subducting seamount. We assume that the normal stress acting on a plate boundary at the seamount is fairly high (+100MPa or more) than the surrounding portion.

The result shows that rupture propagates avoiding the seamount and this pattern is consistent with the result from the subevent analysis by Cummins et al.[2001]. The total slip is relatively high on the deeper western portion of the fault and low on the seamount. This pattern is similar to the tsunami wave analysis, although slip on the shallower western portion and the deeper eastern portion of the fault is different. The difference may caused by some other structures that are not included in the simulation such as deep reflectors and splay faults.

T42D-0957 1330h POSTER

Deep crustral seismic tremor in the Southwest Japan subduction zone

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Deep crustal seismic tremors are discovered by using data of the high sensitivity seismograph network (Hi-net) Japan. The epicenters of tremors are distributed along the 35km depth contour line of the subducting Philippine Sea plate with a length of 500 km from Tokai area, central Japan, to Bungo channel, between Kyushu and Shikoku Island. The tremors occur at the depth of about 30km, near the base of the lower crust and the upper boundary of the plate. Time series of the tremor activity are characterized by active and quiet periods. The active period generally continues for a few days and the quiet period continues for a few months. There is no periodicity in the occurrence of the tremor, however the tremor activity sometimes becomes very high just after a nearby relatively large event occurs. In an active period, location of the tremors moves horizontally in a rather large area. The predominant frequencies of these tremors are in a frequency band of 2 - 10Hz. The magnitude of tremors is very small, so it is very hard to detect the tremor by the normal event detection method. The sequential occurrence and mobility of the source location suggests that the generation of the tremor may be related to fluid. The restricted source depth and horizontal location in the subduction zone indicates that the tremors occur at a specific condition of temperature and pressure with rich fluid. Fluid generated by the dehydration process from the subducting Philippine Sea plate may cause the tremor. Therefore, the tremor might be a direct evidence of the dehydration process and the movement of fluid at the base of the crust or the upper boundary of the subducting slab.

T42D-0958 1330h POSTER

The Thermal Structure and Seismogenic Zone of Warm Subduction Zones: Mexico, Nankai, and Cascadia

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The Nankai, Cascadia and Mexico subduction zones are warm subduction zones. They all have very young incoming oceanic plates (<25 Ma). For warm subduction zones, the seismogenic part of the subduction thrust fault is proposed to be limited to temperatures between 100C and 350C. The thermal controls on the seismogenic zone are investigated using newly-developed thermal models of Mexico and existing thermal models of Nankai and Cascadia. In all cases, the proposed thermal limits are in good agreement with the seismogenic zone inferred from the rupture area of past earthquakes and/or geodetic observations of the crustal deformation associated with the great earthquake cycle.

Despite the similarity in age between the three regions, they exhibit important differences. Both the Nankai and Cascadia regions have a thick sediment cover (1.5 and 3.5 km, respectively), whereas sediment cover is only ~200 m offshore Mexico. The thick sediment cover leads to high subduction thrust temperatures at the trench (90C for Nankai and 200C for Cascadia, compared to <50C for Mexico). Measured heat flow values offshore Mexico are generally much less than the modelled values, which may be indicative of hydrothermal circulation in the upper oceanic plate. This may lead to a local cooling of the oceanic plate and a landward shift in the updip limit of the seismogenic zone. For Nankai and Cascadia, the thick sediment cover is proposed to inhibit hydrothermal cooling, and therefore, the temperature of the subduction thrust is more uniform.

Because the Mexican subduction thrust is cooler, the brittle part of the fault extends to depths of ~40 km. At these depths, even very weak faults may generate non-negligible frictional heating. A small amount of frictional heating, corresponding to an effective coefficient of friction of 0.04, is required by the Mexico models to match the shallow (~25 km) rupture area of past megathrust earthquakes. The brittle part of the Nankai and Cascadia faults is limited to depths less than 20 km, and thus, the effects of frictional heating are negligible.

T42D-0959 1330h POSTER

Numerical Modeling of Thermal Structure in an Accretionary Prism at Nankai Trough Subduction Zone

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The aim of this study is to develop a numerical model of thermal structure in the accretionary prism of Nankai subduction zone, southwest Japan. The Nankai subduction zone is an area where a scientific drilling into seismogenic zones is planned for the future deep sea drilling (OD21). In order to determine drilling sites, it is necessary to know an exact location of the seismogenic zones. In particular, the knowledge of the location of the updip limit of seismogenic region is quite important in determining the most feasible drilling locations. On the other hand, it is widely accepted that ambient conditions, such as temperature, pore fluid distributions and so on, play an important role in the occurrence of earthquakes. Therefore, it is required to know the thermal structure and fluid distributions in the accretionary prisms in order to estimate the depth range of seismogenic regions at the Nankai trough subduction zone.

We develop a numerical model of heat transport and fluid migration which simulates the distributions of temperature and pore fluid in accretionary prisms. Our preliminary results show (i) that the surface heat flow decreases as the accretionary prism thickens landward, and (ii) that the profile of surface heat flow has a slight peak near the deformation front which comes from pore fluid migration driven by the compaction of sediments. These results are qualitatively consistent with the observed heat flow profile at the Nankai accretionary prism. By carrying out further calculations, the thermal structure in the accretionary prism at the Nankai subduction zone will be discussed.

T42D-0960 1330h POSTER

Magnetic anomalies over the Shikoku Basin through Nankai Trough

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A major characteristic of the geomagnetic anomaly map covering the Nankai trough and Shikoku Basin is a series of magnetic lineations aligned NW-SE that are clearly visible oceanward of the trough but gradually disappear to the NW across the axis. Oceanic crust in the Shikoku Basin is carried in the movement of the Philippine Sea plate, and it is moved to the north-northwest with a speed of 4 cm/year. Magnetic lineations are clear up to the trough axis, with rapid attenuation landward of the axis.

These features may extend as much as 100 km landward, because the Curie point depths are 20 km at the trench axis and decrease to approximately 15 km at distances of 100km landward (Okubo, 1984; Tanaka et al., 1999). The depth of the subducting plate boundary at 100km landward from the trench axis is only 10 km, with a temperature estimated from BSR observations of 250-300 degrees. According to the thermomagnetization curve the magnetic anomaly should attenuate by only 20-30 % in this temperature range, so we expect the magnetic lineations to still be observable 100 km landward from the trench axis. However, observation data do not show clear continuous lineations extending landward from the trough axis.

This study used geomagnetic anomaly data provided by the GSJ's East Asia magnetic anomaly map, the Hydrographic Department, JAMSTEC, and NOAA, NGDC. The analysis aimed at determining the origin of total magnetic force and lineations and estimating their distribution.

The main component of total magnetic force is 300 nT (P-P) at 50 km south of the trench axis, which can be modeled with a 6-7 km thick oceanic crust with 7 A/m magnetization. Along the track line just on the trench axis, a 5 km thick crust is required to explain the magnetic profiles. At 50 km north of trench axis, only 2 km thick crust is needed. One potential mechanism for reducing the magnetic amplitude is low temperature chemical demagnetization. The other possibility is horizontal dislocation of oceanic crust along active faults (such as splay faults).

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T42D-0961 1330h POSTER

Geological and Topographical Features of the Zenis Ridge

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The Zenis Ridge locates SE part of the Nankai trough, and appears with a NE-SW direction from Izu-Ogasawara Arc (IOA) to Shikoku Basin. R/V Yokosuka bathymetrical survey and Shinkai 6500 dive survey were carried out in order to study the lithology and tectonics around the Zenis ridge. This ridge is composed three continual blocks such as 1) NE block, 2) Central block, and 3) SW block from east to west. The water depth of this ridge increases southwestward, and maximum depth is about 4000m at the southernmost of SW block. NE block develops as a part of IOA. Steep slope developed on the northern flank, but different topographical character such as valleys with gentle slope are observed on the southern flank of this block. On the Central block, steep slope develops on the northern side, but the step terrace with gentle slope expose on the southern side of this block. The northern flank of this block was composing of fresh basaltic to andesitic volcanic rocks. These are typical Island-Arc type volcanic rock, and these rocks show 6.40-5.33Ma (K-Ar age). Well-bedded sand to mudstone exposed along the southern slope of this block. Nannofossil from these sedimentary rocks indicates Late Pliocene (CN 11b to 12a) age. Some NS trend valleys, E-W and NE-SW trend fault blocks are observed around there. Vesicomyidae clams were observed in fractured sediments distributed along this fracture zone. SW block is different from other two blocks on the topographic and geological view. This block tilt to northwestward, and thick sediment are observed by seismic data. MORB type of volcanic rock was sampled from base of this block. Some active fault was estimated around the Zenis ridge based on the seismic survey. However, result of this survey such as topographic features, discovered Vesicomyidae clams and fractured sediment distribution indicate the active fault should exist along the southern foot of this ridge and cold seepage community with active fault formed there.

T42D-0962 1330h POSTER

A Three-Dimensional Reflection Seismic Investigation of Seismogenic Zone, in the eastern Nankai accretionary prism

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We carried out a 3-D reflection seismic survey [$SFJ - KAIKO$] in the eastern Nankai accretionary prism from June to July 2000. The crustal deformation of the eastern Nankai accretionary prism affected by a nearby collision between the Izu-Bonin arc and the central Japan. Several active fault systems were described by many high-resolution seismic data, and proposed that the Tokai and Kodaiba fault systems were derived from a decollement plane. The main objective of our experiment was to image the plate boundary and identify the up-dip limit of seismogenic zone. The 3-D survey covers 45km long and 5km wide area with 51 seismic lines, located about 50km southwest from Omaezaki. We applied the non-iterative Kirchhoff prestack time migration method (Matsushima et.,al 2001) with stacking velocity analysis to our 3-D data. The processed 3-D data gives us a significantly clear image of the thrust faults and the relationship between sediment deformation and thrust activity. A preliminary 3-D interpretation was conducted and leaded the following results.1) The Tokai and Kodaiba thrusts are clearly imaged as out-of-sequence thrusts. 2) Both thrusts are active fault that revealed by the structure of deformed sediments near seafloor. 3) A strong and low frequency reflector can be traced in the entire profile that should be a decollement plane. Tokai and Kodaiba fault systems merged to the decollement plane at same depth. The contact area of the thrust faults and the decollement may be suggesting the up-dip limit of seismogenic zone of the eastern Nankai accretionary prism .The 3-D image will contribute to reveal the mechanism of disastrous earthquakes in the Tokai area.

T42D-0963 1330h POSTER

Processing of the French-Japanese SFJ Survey on the Eastern Nankai Trough

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A cooperative French-Japanese 3D seismic survey has been carried out during summer 2000 on the eastern Nankai accretionnary complex in the Tokai area. This survey had several goals, among which the imaging of the main wedge faults (Tokai OOST and Kodaiba fault) and the decollement, and their relationship with a probable subducting body previously evidenced by magnetic anomalies. This area has a complex geological structure and a rather shallow depth (sometimes lesser than 1 s TWT), thus generating strong diffractions and several multiples between the water bottom and the decollement. However, the quality of the acquisition is good, according to the homogeneity of the fold map and navigation QC. After a preliminary post-stack time processing we performed a prestack depth migration of the data. Prior to this processing, we obtained a migration velocity model above the multiple using a stereotomographic algorithm based on locally coherent events picking. Under the multiple, the velocity model was estimated using the curvature of the reflectors on common image gathers in the depth migrated domain. After a standard pre-processing phase, the data were migrated using a raytracing based migration algorithm. The obtained prestack depth migrated images show a good improvement of the detailed structure of the top of the wedge, in comparison with preliminary time poststack processed data. In particular, the Tokai OOST and the Kodaiba faults are better imaged and appear flatter than previously thought, consequently defining more precisely the influence of the subducting body on the wedge deformation.

T42D-0964 1330h POSTER

Extracting 3D Structure From 2D Marine Multichannel Seismic Reflection Data Collected Over the Eastern Nankai Trough

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2D marine multichannel seismic reflection data acquisition is frequently conducted with a component of ocean current across the survey profile. When the normal component of the current is a significant fraction of the ships's speed it forces the streamer far to one side of the ship's trajectory and the direction of the hydrophone streamer is different from that of the survey profile. This configuration allows 2D marine seismic data collection to become a very limited swath 3D survey to one side of the ship track. The obtained 3D data volume is characterized by a very low trace fold, irregular midpoint distribution, variable swath width, and narrow source-receiver azimuth range. Commonly, data from such swath 3D marine surveys are processed by assuming a 2D straight-line geometry and by using standard 2D seismic imaging procedures. This approach is effective when the targeted geologic structures have a 1D geometry, and often very useful for studying mildly dipping 2D features. However, when the dip of the reflectors is steep, or the structures are 3D, accurate imaging can be achieved only by taking into account the 3D character of the data.

We present a method for improved signal alignment before stack and extraction of local 3D structure from swath 3D marine data. The method requires the true source and receiver coordinates and is based on a traveltime equation that takes into account the three dimensionality of the data. We show the results obtained by applying this method to seismic reflection data acquired over the eastern Nankai Trough during Kaiko-Tokai French-Japanese project. For this survey the Kuroshiro current had a similar speed to that of the ship and for much of the survey the streamer was at nearly 45 degrees to the survey line. The resulting average swath width is about 1 km. The extracted 3D information and increased resolution of the images put better constraints on the geometry of the accretionary prism decollement and thrust structure. The obtained results also help define more precisely the position and geometry of the seismogenic part of the subduction thrust.

T42D-0965 1330h POSTER

Physical properties of the bright reflections from the top of the subducting Philippine Sea plate beneath the eastern Shikoku Island, SW Japan

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Properties across the reflecting interface control amplitude versus offset (AVO) response, reflection polarity, normal incidence reflectivity, and so on. Analyzing the properties of the reflected wave field is useful to know the physical properties of the materials near a reflector. In the summer of 1999, we conducted an onshore-offshore seismic experiment across the eastern Shikoku Island and the Nankai trough. On shore 93 land seismic stations were deployed on a 165-km-long line in the north-south direction. Three explosives were fired as controlled seismic sources. The most remarkable feature of the record sections is that extremely high amplitude reflections (bright reflections) can be recognized. This reflection phase is observed from almost zero offset to large offsets(160km). This phase was interpreted to a reflected wave from the top of the subducting Philippine Sea plate [Kurashimo et al., 2001]. To obtain detailed physical properties of the material between the subducting Philippine Sea plate and island arc crust, it is necessary to analyze the properties of this phase. First, we assumed that only the velocity contrast between the subducting oceanic crust and the island arc crust controls the amplitude of reflection phase. To explain a high amplitude reflection, we need a very large velocity contrast. Next, we add a thin layer between the subducting oceanic crust and the island arc crust, and then the ray tracing method was employed to calculate the wave field . As a result, a slow P-wave velocity, less than 50% of the surrounding layer, is necessary in this thin layer to explain the observed extremely high amplitude reflections. In this study we discuss the physical properties of the bright reflections from the top of the subducting Philippine Sea plate by AVO analysis.

T42D-0966 1330h POSTER

Spatial Variability of Deformation Front Structures in the Nankai Accretionary Prism

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The Nankai margin off southwest Japan is characterized by active convergence, a large accretionary prism, and a thick sequence of incoming hemipelagic sediments. In the Moroto area, a 3-D seismic volume images the undeformed stratigraphy of the Shikoku Basin, landward through a protothrust zone, across the frontal thrust, through several prominent imbricate thrusts, and into a zone of large out-of-sequence thrusts. Interpretation of reflectors in the protothrust zone reveals a high degree of structural complexity, as well as along-strike structural variability. In addition to a prominent protothrust, the protothrust zone contains several smaller incipient thrusts oriented parallel to the frontal thrust, conjugate back thrusts, and numerous small normal faults. Seismic data also reveal complex oceanic crust morphology underlying the incoming sedimentary package. This ocean crust is characterized by a linear, trench-normal structural low, which is likely a remnant of its formative spreading process. The high degree of relief in this basement surface suggests that differential compaction may be responsible for similarly oriented normal faults in the overlying Shikoku Basin sequence. Trench-parallel normal faults, however, are more likely the result of flexure of the downgoing plate as it begins to subduct. The linear basement structural low also coincides spatially with a prominent bend in both the frontal thrust and main protothrust. This prominent bend may be part of a regional landward stepping of the frontal thrust to the north. The protothrust zone marks the transition from an undeformed sedimentary sequence to an accretionary prism exhibiting fold and thrust belt structure controlled by an underlying decollement. Reflectors in the Shikoku Basin sequence, seaward of the main protothrust, show subtle signs of compressional deformation and better constrain the location of the onset of slip on the decollement.

T42D-0967 1330h POSTER

Integration of Leg 196 LWD data and 3-D seismic data in the Nankai accretionary prism: Preliminary interpretations of fluid flow indicators

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Leg 196 of the Ocean Drilling Program (ODP) investigated the interrelationship between the fluid flow regime and deformation in the Nankai Trough accretionary prism. Leg 196 is part of a larger effort to fully characterize the accretionary processes at the Nankai trough that also includes ODP Legs 131 and 190 and a 3-D seismic reflection survey. Logging-while-drilling (LWD) data from Site 808, collected during Leg 196, combined with wireline and core data from Site 1174, collected during Leg 190 provide details about fluid expulsion, deformation, diagenesis, and compaction at both the proto-thrust and frontal thrust of the Nankai accretionary prism. These data can be used to calibrate the 3-D seismic reflection data. At Site 808, a clear negative-polarity reflection is present, while at Site 1174 there is no fault-plane reflection, making these sites useful end-member cases for modeling. Seismic modeling at these sites seeks to differentiate between reflection polarity caused by differences in consolidation of the overthrust and underthrust sections and the presence of fault-channelized fluids. Preliminary interpretations of the first three thrust faults of the accretionary prism show consistent negative polarity fault plane reflections with a concentration of high amplitudes where each of the three faults roll over to diminish in dip towards the seafloor. To interpret fault zone reflections as fluid indicators, we present seismic modeling results of the physical causes of these variable thrust fault images at the deformation front. In addition, we present 3-D impedance surfaces for the remaining thrust faults, from the deformation front to the first out-of-sequence thrust that we examine for fluid flow indicators based on the LWD-seismic integration at Sites 808 and 1174.

T42D-0968 1330h POSTER

Preliminary Results from Integration of 2D PSDM and ODP Leg 196 LWD Velocity Data in the Nankai Accretionary Prism

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The Nankai Trough "Muroto Transect" has been extensively studied, with 3 Ocean Drilling Program (ODP) legs (Legs 131, 190, and 196), numerous multichannel seismic (MCS) reflection surveys, including a 3D survey in 1999, and several refraction studies. As ODP sites only provide point measurements of structure and physical properties, it is necessary to use other methods, such as MCS reflection studies, to interpolate between sites. 2D prestack depth migration (PSDM) velocity analyses have been carried out on several lines extracted from the 3D MCS data set. Initial lines were chosen to intersect the latest ODP sites (Sites 1173-1175,1178, Leg 190; Sites 808 and 1173, Leg 196). Primary results of these 2D PSDM analyses include more accurate depth sections along the Muroto transect, that are vital for accurate interpretation of physical property and structural information between the ODP sites. Additionally, strucutres have been made clearer through the 2D PSDM, including brightening of the proto-thrust and several backthrusts, as well as bringing out the decollement reflector more continuously. Our PSDM velocities roughly correlate with the core and wireline velocity measurements collected on ODP Legs 131 and 190. As core and wireline velocity measurements are made long after the hole has been drilled, they may not represent in situ values. However, PSDM-calculated velocities have been shown to closely approximate in situ velocities; this may explain the misfit. During ODP Leg 196, Logging-While-Drilling (LWD) measured in situ physical properties at Sites 1173 and 808. With the ISONIC tool, in situ seismic velocities were be accurately measured. The PSDM velocities are shown to correlate significantly better with the ISONIC velocities from Leg 196 than with the core and wireline velocities from previous legs. This confirms that the PSDM velocities calculated are representative of in situ velocities in the prism. Therefore, we can interpolate other physical property measurements (e.g., porosity) between the drill sites, using our PSDM velocities for calibration.

T42D-0969 1330h POSTER

Fault Systems off Shikoku Nankai Trough Accretionary Prism Deduced From JAMSTEC and JNOC MCS Data

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We reconstructed the 3-dimensional fault system distribution in the Shikoku Nankai accretionary prism, offshore southwestern Japan using Multi-Channel Seismic Reflection Survey (MCS) data. It is important to know the distribution of fault systems in an accretionary prism. These data were used to infer the development history of the prism through geological time, state of stress in the crust and relationship between seismogenic and branched and/or spray faults (for the case of active faults). The Nankai Trough is the topographic expression of the subduction boundary. The Philippine Sea Plate is subducting to the northwest beneath the Southwestern Japan arc at a rate of 2-4 cm/yr, approximately normal to the plate margin. Sediment accretion is occurring here, so that a lot of active deformation including faults and folds develops in this area. We used the following data set: Japan Marine Science and Technology Center (JAMSTEC) MCS data obtained by R/V Kairei during 1997 to 1999, and the Japan National Oil Company (JNOC) MCS data published in 1991. Four fault systems, decollement zone, thrust faults, strike-slip faults, and normal faults, are recognized in this area. Thrust faults, mostly dipping landward, develop from the Frontal Thrust Zone (Moore, Taira, Klaus, et al., 2000) through the Large Thrust Slice Zone. Some back-thrust faults are also found. The decollement zone can be recognized from the outside of the deformation front to the Large Thrust Slice Zone. Some thrust faults develop as an extension from the tip of the decollement zone, and some cut the decollement zone. Occurrences of normal faults are mainly related to forearc basins. Some form half grabens or margins of forearc basins, while some occur as large slumps in the basin. Lateral faults mainly develop between the regions, which the thrust faults and the normal faults dominate. Particularly, they occur at the eastern scarp of the topographic indentation off Tosa-Bae, where one of the Kinan Sea Mounts is presently subducting. Based on the distribution of fault systems, we concluded that they are formed during the development of the Nankai accretionary prism, and that the subducting Kinan Sea Mount played an important role in lateral fault formation.

T42D-0970 1330h POSTER

Rupture model for the 1944 Tonankai earthquake from waveform inversion of teleseismic and regional seismograms

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We present a rupture model for the 1944 Tonankai earthquake ($M_S = 8.1$) that occurred at the northeastern end of the Nankai trough. The dataset that we used consists of local and regional strong-motion records as well as teleseismic P and S wave recordings. A total of 19 strong motion and 28 teleseismic components were digitized and inverted using a multiple time-window least squares inversion scheme. The fault is represented by a rectangular grid of 200 × 140 km dipping 20° to the northwest, parallel to the trench axis, with gridsizes of 20 × 20 km. We used the hypocenter location of Kanamori (1979) as starting point of the rupture. The maximum slip found is on the order of 4 meters with a final moment of 3.5×10^{28} dyne.cm. These results are consistent with models based on tsunami and geodetic data. In order to estimate the resolution of the inversion we have run many different scenarios, with varying rupture speeds and different durations as well as forward models, the latter especially to delineate the rupture extent at the northeastern end of the fault. We will discuss these results and our preferred rupture model, and the consequences for future earthquake scenarios in the Nankai trough and surrounding regions.

T42D-0971 1330h POSTER

An application of the crustal deformation simulator to seafloor

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The objective of this study is to establish a quantitative evaluation method for crustal deformation by introduction of FEM stress-deformation analysis to our simulator. As a case study, we consider the tsunami source area caused by the 1993 Hokkaido Nansei-oki earthquake, Japan.

Principal Results

1. Proposal of a new method to evaluate seafloor crustal deformation

We proposed a new method to evaluate crustal deformation around earthquake source area using FEM stress-deformation analysis. In this method, we take account of heterogeneity of crustal structure under the seafloor with the in-situ geological and geophysical observed data.

2. Development of the correction method for aftershock distribution

We corrected the JMA (Japan Meteorological Agency) hypocenters of aftershocks occurring just after the mainshock of the 1993 Hokkaido Nansei-oki earthquake making reference to the OBS (Ocean Bottom Seismograph) hypocenters observed in another period. After this correction, we could acquire precise shapes and sizes of the mainshock faults with high-resolution.

3. Establishment of the evaluation method for crustal deformation using FEM

We constructed a 3-D finite element model of the seafloor including the shape of the mainshock faults estimated from the corrected hypocenters. As a result of an FEM stress-deformation analysis to this model with

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temporal change, we could find subsidence in Okushiri island consistent with the observed one.

T42E MC: 310 Thursday 1330h

The Physics and Mechanics of Compressive Failure: From Faulting to Ductile Flow I *(joint with S, MR, HG)*

Presiding: **C E Renshaw,** Dartmouth College**; E M Schulson,** Dartmouth College

T42E-01 1330h

Coupled Evolution of Damage and Fluid Flow: A Unified Permeability-Porosity-Stiffness Relation.

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We present a formulation for mechanical modeling of interaction between fracture and fluid flow. The new model combines the classical Biot's poroelastic theory together with a damage rheology model. The theoretical analysis based on the thermodynamic principles, leads to a system of coupled kinetic equations for the evolution of damage and porosity. We generalize the widely used permeability (k)-porosity (ϕ) relation ($k=k_o\phi^n$), by accounting for the effect of damage intensity on the connectivity:
$k=k_o\phi^n\alpha^m$,
where α is the damage intensity variable. This new damage-permeability relation together with the coupled kinetics of damage and porosity evolution reproduces a wide range of realistic features of rock behavior. We constrain the model variables by comparisons of the theoretical predictions with laboratory results reporting porosity and permeability variation of rock samples during isostatic and anisotropic loading. The development provides an internally consistent framework for simulating coupled evolution of fracturing and fluid flow in a variety of practical geological and engineering problems such as: nucleation of deformation features in poroelastic media and fluid flow during seismic cycle.

T42E-02 1345h

Seismic and Micromechanical Studies of In situ Compressive Failure

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Our fundamental understanding of how microfractures progressively weaken rocks and in turn how this contributes to macro-deformation processes is limited. However, recent advances in particulate mechanics now mean fracture processes can be modelled dynamically to study the micro-mechanics of fracturing in rock. In addition, advances in recording and analysing very high frequency acoustic emissions (AE) allow for detailed examination of micro-cracking. We use these particle models and AE techniques to test specific hypotheses about natural and induced rock fracture processes at an intermediate scale (between classic lab and nature) by examining compressive failure in an underground laboratory in granitic rock.

During the excavation of the underground laboratory seismic activity was recorded using an array of 16 triaxial accelerometers positioned to give optimal focal coverage around a tunnel. The data collected on these sensors were processed to provide locations, magnitudes and source mechanism information about compressive failure around the tunnel. The dynamic excavation response was modelled in 2D using the Particle Flow Code (Itasca Consulting Group). The rock properties used in the model were first calibrated by undertaking a series of simulated uniaxial lab tests and comparing the results to actual laboratory tests undertaken on the granite. To simulate the time-dependent response of the tunnel a stress-corrosion mechanism was employed in the model. In the excavation simulation, we found that the spatial and temporal evolution of the seismicity and the magnitude distributions replicated the in situ seismicity. As part of the PFC modelling, source mechanisms (moment tensors) were also computed for the events recorded during the dynamic simulation. Although a direct comparison of the mechanisms cannot be made as the simulation was performed in 2D, the results are compatible with those that have been observed during processing of the real events.

Hazzard J.F., Young R.P., and Maxwell S.C., (2000). Micromechanical modelling of cracking and failure in brittle rocks. Journal of Geophysical Research, 105, 16,683-16,697.

URL: http://www.liv.ac.uk/seismic

T42E-03 1400h

Acoustic Emission Activity and Spatial Distribution of Damage Associated with Compaction Band Formation

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Compaction band has been observed as a localized failure mode in porous sandstones, at stress states that are associated with the transitional regime from brittle faulting to distributed cataclastic flow. Detailed microstructural observations were conducted on the Bentheim, Berea, Boise, Darley Dale and Rothbach sandstones with porosities ranging from 13% to 35% to delineate and quantify the spatial distribution of damage associated with the development of compaction bands. Significant grain crushing and porosity reduction are evident in the localized bands, with crack densities up to 5 times greater than those in areas outside the bands. Two different patterns of strain localization can be distinguished: diffuse conjugate shears at relatively high angles, and discrete compaction bands subperpendicular to the maximum compression direction. Whereas the development of diffuse bands is characterized by the continuous accumulation of acoustic emissions (AE), discrete bands are associated with episodic surges in AE that are characterized by an overall strain hardening trend punctuated by episodic stress drops. The number of discrete bands correlates with the number of AE surges and stress drops. Preliminary permeability measurements indicate appreciable reductions of permeability during compaction band development.

T42E-04 1415h

Deformation Bands as Linear Elastic Fractures: Progress in Theory and Observation

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Deformation bands (DBs) are thin, tabular, bounded features of highly localized shear and/or compaction that commonly occur as systematic and pervasive arrays in porous sandstone. They also constitute an active area of theoretical and experimental research into the compressive failure of granular materials. Based on our ongoing study of DBs in the field, we propose that they originate at stress concentrations and propagate as brittle fractures in a linear elastic medium. Furthermore, we suggest that individual DB morphology is largely dominated by the closing (anti-mode I) component of the displacement discontinuity accommodated.

The notion of DBs as "anti-cracks" akin to pressure solution surfaces is not new. But close examination of real DB arrays within the unifying context of linear elastic fracture mechanics is needed to add depth and bring quantitative rigor to our understanding of the phenomenon. Thus, we are building a body of detailed data based on field observation and thin-section analysis to substantiate and expand our central hypothesis, while also laying the foundation for an effort to replicate realistic DB arrays using numerical modeling techniques. Our field effort focuses on the Jurassic Aztec Sandstone as exposed in and around the Valley of Fire State Park, Nevada. This area offers expansive and varied DB exposures within a thick and relatively consistent sequence of dune-dominated aeolian sandstone.

We will present interim results, interpretations and conclusions specific to the elastic nature of DBs, in particular comparing our data to the three distinct fracture-tip models: the dislocation, and the crack with and without cohesive end zones. Each of these models predicts substantially different near-tip stress fields for the same material under the same remote loading conditions, leading to different expectations for basic DB shape, structure, and propagation and mechanical interaction behavior. These expectations will be compared to and judged against our field-based observations.

T42E-05 1430h INVITED

Predictions for Localized Compaction Bands

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Compaction bands are narrow, planar zones of localized pure compressive deformation (without shear) that form perpendicular to the direction of the maximum compressive stress. They have been observed in porous sandstones in the laboratory under conditions for which uniform (non-localized) compression is also a possible mode of deformation and in the field. Because the porosity and permeability in the bands is less than in the surrounding material, formation of these bands in reservoirs and aquifers can dramatically alter the character of the fluid flow. Olsson (*JGR*, 1999) has pointed out that conditions for the occurrence of compaction bands can be derived by the same approach used by Rudnicki and Rice (*J. Mech. Phys. Solids*, 1975) to predict the onset of shear bands: determining the conditions on the constitutive parameters for which localized deformation is an alternative to uniform deformation. This procedure is applied to the predict the onset of compaction bands in the axisymmetric compression test for a transversely isotropic material (with the isotropy axis coinciding with the specimen axis) described by a linear relation between stress-rates and strain-rates. Compaction bands are first predicted to occur when $E = -(9/2)r\nu K$, where E is the tangent modulus (slope of stress vs. strain curve), ν is the negative of the ratio of increments of lateral to axial deformation (at constant confining stress), r is the ratio of axial to lateral stress increments causing zero axial deformation and K is a modulus relating increments of lateral stress and strain. In axisymmetric compression experiments, compaction bands are typically observed on relatively flat portions of the stress-strain curve indicating that $E \approx 0$. Some experimental evidence suggests that the deformation is nearly uniaxial, $\nu \approx 0$ but the non-uniform deformation makes precise measurements difficult. Shear bands (sometimes at low angles to the specimen axis) are frequently observed in conjunction with or in the absence of compaction bands. The predictions of both depend sensitively on the constitutive formulation and, in materials modeled by both a shear yield surface and a "cap", on the intersection of the two surfaces.

T42E-06 1450h

A New Class of Microstructures Associated with Transformation-Induced Faulting

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Previously, experiments on transformation-induced faulting during the olivine to spinel transformation in Mg_2GeO_4 have provided an increasingly clear picture of the microstructural evolution of spinel-filled anticracks under loading and the coalescence of individual anticracks into through-going faults. We report here a new type of stress-induced transformation microstructure that also leads to bulk shear failure, discovered in a new Mg_2GeO_4 starting material with a larger average olivine grain size (150 μm) and much smaller average enstatite grain size (5 μm) than that used in previous studies. Electron microscopy shows thin (120-1000 nm) planar zones of nanocrystalline (10-40 nm) spinel which form by preferential transformation of low angle boundaries in deformed olivine. These zones develop rapidly after approximately 25% bulk strain. As these zones develop into a network with increasing strain, specimens weaken at an accelerating rate and ultimately can fail in shear. The rate of weakening preceding bulk failure correlates with the degree of development of the planar zones. In failed specimens and in those unloaded before bulk failure, individual zones show evidence of shear offsets, suggesting that the strain weakening may be due to localized failures