T52D-10 1610h

Oldest ophiolite - 2.8 Ga boninite series of a supra-subduction zone ophiolite from the North Karelian greenstone belt, NE Baltic Shield, Russia

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Late Archean subduction-related assemblages of the North Karelian greenstone belt, NE part of the Baltic Shield, Russia, reveal the oldest known boninite series occurring at least in two area of the belt. The first area referred to here as the Khizovaara structure shows apparent evidence of a late Archean ocean-island volcanic arc collage formed during two distinct tectonic episodes nearly 2.8 Ga ago. The second area named as the Iringora structure discloses unique features of an ophiolite stratigraphy, including not only gabbro or lava units, but also remnants of a sheeted dike complex. The major and trace element chemistry of the Iringora ophiolitic gabbro, dike and lava units suggests a comagmatic series with a continuous compositional variation from more primitive mafic to strictly boninitic melts. In terms of major- and trace element abundance, the boninite series of the North Karelian greenstone belt is practically indistinguishable from the Group I and II of the Troodos upper pillow lavas defined by Cameron (1985). These occurrences strongly suggest that late Archean subduction-related processes evolved boninite-hosting SSZ ophiolites have not changed substantially over the past 2.8 Ga.

URL: http://geo.tv-sign.ru/present/karelia/FrameSet.htm

T52D-11 1625h INVITED

Tectonic implications for the occurrence of ocean floor, hotspot, and island arc materials within accretionary prisms: Examples from the Mesozoic-Cenozoic NW Pacific Rim

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On-land Mesozoic-Cenozoic accretionary prisms exposed in Japan commonly have basaltic rocks incorporated as blocks into melanges or fault zones during a prolonged history of subduction and/or obduction. Chemical signatures of these basaltic rocks and their mode of occurrence with sedimentary covers and/or associated sedimentary rocks indicate that most of these isolated small basaltic blocks consistently display a WPB chemistry, whereas large slabs of basaltic rocks around the Izu Arc collision zone show MORB chemistry with rare examples of IAT, BABB, and/or WPB affinities. Comparing with the present uniformitarian examples of convergent plate boundaries in the western Pacific that we know through the DSDP and ODP projects and submersible and seismic surveys, we can interpret some of the basaltic material with WPB affinity in the Japanese accretionary prisms as relict edifices of seamounts with hotspot origin. These hotspot-related basaltic rocks are commonly associated with reefal limestones and were incorporated into continental margin melanges either by submarine sliding from the downgoing oceanic plate or by shallow-level offscraping along decollement surfaces during the subduction of oceanic plates. Older, uplifted parts of the fossil accretionary prisms on the continent side further inward from the trench where the deeper levels of accreted material are exposed include larger amounts of basaltic blocks. This observation suggests that significant amount of underplating might have occurred in the deeper levels of oceanic crust along decollement zones at structurally lower depths. The metamorphic belts (e.g.Sambagawa, Chichibu, Shimanto etc.) have commonly alkaline rocks or plateau-type E-MORB basalts without any trace of N-MORB rocks with rare special exceptions.

Besides these ordinary accretionary prism examples formed by a simple plate subduction system, another type of accretion resulting from island arc or ridge collision is observed to have occurred in both the eastern and western Izu Arc collision zone since the Miocene. The arc/ridge collision caused the incorporation of a particular assemblage of basaltic rocks in this tectonic accretion system which we interpret as an ophiolite. These gophiolitich rocks are composed of various types of basaltic to rhyolitic, effusive and intrusive, dismembered, disrupted, sheared and faulted rocks that are locally associated with some hotspot and island arc igneous rocks and pelagic sedimentary rocks. This ophiolite assemblage is widely distributed particularly in the trench-slope break or within the forearc sliver boundary in the Circum Izu region. Deformation and metamorphism in these settings are weaker at shallower levels than those in the accretionary prisms, other than the Izu Arc collision zone. Based on these examples from Japan, we infer that ocean floor, hotspot, and island arc rocks become accreted into active continental margins either through ordinary subduction-accretion processes in a non-collisional subduction system or by obduction-accretion processes in a collisional island arc system.

T52D-12 1640h

Multi-stage Evolution of the Tertiary Mineoka Ophiolite (Boso Peninsula, Japan) at a TTT Triple Junction in the NW Pacific as Revealed by New Geochemical and Age Constraints

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The Pacific, North American, and Philippine Sea Plates are adjoined at a TTT-type triple junction 350 km SE of the Boso Peninsula in central Japan where the Japan, Izu-Bonin, and Sagami Trough Trenches intersect. The Mineoka ophiolite, outcropping in the southern Boso Peninsula, has been situated in a unique tectonic setting in the Izu Arc collisional zone on the SE-concave Honshu Island since the middle Miocene. We discuss the mode of occurrence, geochemistry, and radiometric ages of the basaltic and other igneous rocks from the Mineoka ophiolite to verify the origin and tectonic implications of these rock assemblages. The ophiolitic rocks are composed mainly of tholeiitic pillow basalts and doleritic sheeted dikes, alkali-basaltic sheet flows, and calcalkaline dioritic to gabbroic plutons. The tholeiitic basalts show variable trace-element compositions ranging from mid-oceanic ridge to island-arc type. The alkali-basalts have a within-plate affinity. Ar-Ar and K-Ar dates yield ages of 40-50 Ma and 110 Ma for the tholeiitic basalts, 20 Ma for alkali-basalts, and 20 to 40 Ma for the calcalkaline plutonic rocks. These age brackets are inconsistent with the known ages from the Pacific or the Philippine Sea Plates; we therefore infer that the Mineoka ophiolitic assemblage was part of an oceanic plate, called the gMineoka Plateh. The Mineoka Plate underwent an island-arc volcanism in the Miocene as a result of subduction initiation at a fracture zone or a transform fault system due to a change in the position of the Euler rotation pole of the Pacific Plate 43-42 Ma. Rift volcanism associated with back-arc basin opening might have occurred within the Mineoka Plate shortly after the establishment of this subduction zone. Eruption of within-plate-type alkali basalts in the ophiolite likely took place near the paleo-Honshu continental arc just before the emplacement of the Mineoka ophiolite into the Japanese continental margin.

T52E MC: 310 Friday 1330h

Nankai Seismogenic Zone: GPS, Earthquakes, Relection Seismology, and Comparisons to Costa Rica *(joint with OS, S)*

Presiding: **H Mikada,** Japan Marine Science and Technology**; S Schwartz,** UC Santa Cruz

T52E-01 1330h INVITED

Crustal deformation along the Nankai Trough through an entire earthquake cycle: a retrospective view with present GPS data

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Crustal deformation along the Nankai Trough provides one of the most complete deformation records associated with an earthquake cycle at subduction zones. Triangulation and leveling surveys starting from the late 19th century have revealed typical coseismic, postseismic, and interseismic deformation related to plate boundary megathrust events. In addition, recently deployed Japanese nationwide continuous GPS array (GEONET) provides very precise information about an interseismic strain accumulation process. Not only horizontal but also vertical displacement rate is estimated at every GPS site, showing landward motion and inland uplift due to interplate locking. More importantly, daily coordinate solution has revealed that interseismic deformation is not perfectly steady and at least two episodic slow slip events have occurred along the Nankai Trough recently.

I will overview the spatio-temporal pattern crustal deformation during the last earthquake cycle based on conventional geodetic survey data and recent continuous GPS data. Present GPS-derived interseismic deformation pattern resembles those derived from conventional geodetic surveys in old days. But the GPS data yields smaller (about 60%) angle change rates of the triangulation network than the old data, implying time-dependent deformation rate changes and a possibility of episodic deformation events. GPS-based uplift data shows wider uplift areas to further inland compared with previous leveling results. Recently slow thrusts event with a duration of more than several months are found around the Bungo Channel (Hirose et al., 1999) and in the Tokai district (Ozawa et al., 2001). I review old triangulation as well as leveling data in the light of these new findings. Especially after the 1946 Nankaido earthquakes, postseismic deformation with a time constant of 5-30 years was found in and around the Shikoku island. On the other hand, Kimata and Yamauchi (1998) reported periodic changes in baseline shortening rates every 6-8 years in the Tokai area. These old observation can be interpreted as a result of slow slip events. It is reasonable to assume these slow events have repeatedly occurred in the past. These new findings are crucial to a proper understanding of the deformation cycle along the Nankai Trough.

T52E-02 1345h

A Possible Precursor of an Anticipated Subduction Zone Thrust Earthquake in the Tokai Region, Central Japan, Detected by a Continuous GPS Network Measurements

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The Tokai region is located along the Pacific coast of central Japan and about 200 km to the south west of Tokyo. The Suruga trough, a subduction plate boundary between a continental plate and the Philippine Sea Plate, runs just off shore of this area. This region is a well known seismic gap along the Suruga-Nankai trough. Continuous GPS data since 1994 and historical geodetic survey data for about 100 years consistently suggest a steady strain accumulation in this region until recently. Since the beginning of 2001 we detected a change in crustal deformation rates around the Tokai

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region using continuous GPS data. This change is preceded by transient phenomena associated with a large seismo-volcanic event in the Izu islands during July-October 2000. This 2000 Izu islands event caused a significant crustal deformation of up to 3 cm in the Tokai and Kanto regions, central Japan. After October 2000, the effect of the Izu islands activity faded out and the Tokai and Kanto regions returned approximately to a previous normal state of crustal deformation. However, from March 2001, another stage of ground displacements started in the Tokai region. Detrended GPS coordinate time series data show southeastward motion of about 1 cm for the period between March and August 2001. Taking into account the effect of the 2000 Izu islands event, which still continues with much less activity than in summer 2000, we estimate slip motion on the plate boundary in the Tokai region. The inversion result shows that a slow thrust slip occurs on the plate boundary around Lake Hamana in the western Tokai region. Estimated seismic moment due to the slow slip has been increasing linearly from March to August 2001, while the slip area seems to be expanding to the east to a more tightly coupled area for the same period. The slip area cannot be well resolved in the eastern Tokai region because the effect of the Izu islands activity also explains a part of the observed southeastward motion there. However we cannot rule out a existence of a slow slip in the eastern Tokai region, a presumed central source region of the forthcoming Tokai earthquake. In any case the existence of change of deformation rate is now significant considering the accuracy of GPS measurements. Intensive monitoring on the temporal evolution of this phenomenon and timely update of a physical model are necessary.

T52E-03 1400h INVITED

Seismological Characterization of the Nankai Trough Seismogenic Zone from Active / Passive Seismic Studies

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Detailed rupture processes and tsunamigenic slip distributions of the 1944 Tonankai and the 1946 Nankaido earthquakes become clear due to recent progress of seismic, tsunami and geodetic data analysis. The most recent sub-events studies of the 1946 event (Hashimoto and Kikuchi, 1999; Cummins et al., 2001) showed that the first sub-event occurred beneath the cape Shiono following the initial break at 50 km off the Kii peninsula, then the second sub-event jumped downward off the central Shikoku island. The tsunami wave data inversion (Tanioka and Satake, 2001) also showed a similar patter of the co-seismic slips. On the other hand, active seismic studies to reveal the seismogenic zone structure have been widely carried out in the Nankai trough since the last five years. A subducted seamount colliding to the Japanese island arc crust was successfully imaged off the cape Muroto by an extensive active seismic survey. This subducted seamount is proposed as a barrier preventing a lateral propagation of the co-seismic rupture during the 1946 event. In terms of the rupture process of the 1944 event, both seismic and tsunami data (Kikuchi and Yamanaka, 2001; Tanioka and Satake, 1999) show the co-seismic ruptures were concentrated at the east of the Kii peninsula and did not extend to the Tokai district. A key question is, therefore, if there is significant structural factor to prevent the rupture in this area. Even though it is proposed the paleo-Zenisu ridge might be subducted in the eastern Nankai trough, no clear seismic image has been obtained. In July to August of 2001, therefore, an active seismic study using a super densely deployed OBS array was performed off the Tokai district in order to give an ultimate answer to the question above. A series of passive seismic studies off the cape Muroto, moreover, demonstrated a possibility of monitoring micro-earthquakes, which may reflect a state of stress in the seismogenic zone. The observed micro-earthquake activity seems to be classified into two clusters; one is at the plate interface and the other is in the uppermost mantle. Less activity was observed within the subducted oceanic crust. A seismic-aseismic transition zone, which is considered to be closely related to a locked-unlocked zone at the up-dip limit of the seismogenic zone, has not been clearly observed. This is probably due to coverage of the OBS array. We, thus, plan to have a more large scale OBS array off the Kii peninsula to investigate if there exist the seismic-aseismic transition zone at the up-dip limit of the proposed rupture zone.

T52E-04 1415h

Characteristics of the Central Costa Rican Seismogenic Zone Determined from Microseismicity

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Large or great subduction zone thrust earthquakes commonly nucleate within the seismogenic zone, a region of unstable slip on or near the converging plate interface. A better understanding of the mechanical, thermal and hydrothermal processes controlling seismic behavior in these regions requires accurate earthquake locations. Using arrival time data from an onland and offshore local seismic array and advanced 3D absolute and relative earthquake location techniques, we locate interplate seismic activity northwest of the Osa Peninsula, Costa Rica. We present high resolution locations of ~600 aftershocks of the 8/20/1999 Mw=6.9 underthrusting earthquake recorded by our local network between September and December 1999. We have developed a 3D velocity model based on published refraction lines and located events within a subducting slab geometry using QUAKE3D, a finite-differences based grid-searching algorithm (Nelson & Vidale, 1990). These absolute locations are input into HYPODD, a location program that uses P and S wave arrival time differences from nearby events and solves for the best relative locations (Waldhauser & Ellsworth, 2000). The pattern of relative earthquake locations is tied to an absolute reference using the absolute positions of the best-located earthquakes in the entire population. By using these programs in parallel, we minimize location errors, retain the aftershock pattern and provide the best absolute locations within a complex subduction geometry. We use the resulting seismicity pattern to determine characteristics of the seismogenic zone including geometry and up- and down-dip limits. These are compared with thermal models of the Middle America subduction zone, structures of the upper and lower plates, and characteristics of the Nankai seismogenic zone.

T52E-05 1430h

The Costa Rica M_w=6.9 Underthrusting Earthquake: Aftershock Focal Mechanisms and Deformation Associated with Seamount Subduction

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The 1999 M_w=6.9 underthrusting earthquake northwest of the Osa peninsula, Costa Rica, occurred only a few weeks prior to deployment of a temporary regional network of land and ocean bottom seismometers, providing an excellent opportunity to combine studies of the mainshock rupture process with an examination of the aftershock sequence. This earthquake occurred in an area of seamount and Quepos Plateau subduction, and analysis of its source process suggests rupture of a simple asperity consistent in size to the incoming high-topography features on the subducting plate. High precision locations of aftershocks recorded by the temporary land and OBS network define the plate interface in this region. They also show a seismicity gap, consistent with the rupture area of the mainshock, which may represent the main asperity that ruptured during the earthquake. Here we present focal mechanisms for aftershocks of the event recorded by the temporary land and OBS network. Mechanisms are determined using a gridsearch inversion of P, SH, and SV amplitude ratios. Synthetic seismograms are first computed for fundamental fault orientations, and peak amplitudes for P, SH, and SV are determined. We then combine the fundamental fault amplitudes for all possible strike, dip, and rakes to determine the fault orientation that minimizes misfit between the observed and synthetic P/SH, P/SV, and SH/SV ratios. Preliminary results show diversity in the mechanisms, ranging from underthrusting consistent with subduction in the region to thrust mechanisms with large strike-slip components. These are similar to previous studies of other earthquake mechanisms in the area determined by permanent land network data. The diversity in earthquake focal mechanisms is interpreted in terms of deformation caused by the subducting seamount and Quepos Plateau features.

T52E-06 1445h

Characteristics of the Nicoya Peninsula, Costa Rica Seismogenic Zone from Microseismicity

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Most of the world's great earthquakes occur along the seismogenic portion of the thrust interface at subduction zones. The geometry and degree of plate coupling along the seismogenic region of subduction zones are not well determined, making it difficult to understand its mechanical behavior. These regions are difficult to study as they generally occur offshore. The Nicoya Peninsula in Costa Rica, however, is directly over the seismogenic zone. We deployed an 18 month 20 station seismic network directly above the most active portion of the plate interface allowing more direct examination of the region's seismicity. For 6 months, the network was augmented by 14 offshore seismometers providing dense seismic coverage from the trench land-ward 100 km.

We report earthquake locations of $\sim$ 450 events defining the seismogenic zone. We locate earthquakes using a local earthquake tomography program, SIMULPS (Thurber and Eberhart-Phillips, 1992) using a 3-D velocity model constrained by the local national network. Events were also located using a relative relocation program, HYPODD (Waldhauser and Ellsworth, 1990) to minimize errors from unmapped structure. Close agreement between these two methods suggests little structural bias in locations. Focal solutions for many larger events (Ml > 3) indicate simple thrust, consistent with subduction on the plate interface. Though interplate seismicity is present from 10 to 40 km depth, most events concentrate along a narrow band between 14 to 22 km. This activity, which best defines the upper limit of the seismogenic zone shallows by 4° to the southeast. The majority of interplate seismicity is beneath the 100° C isotherm (Harris et al., 2001), consistent with other subduction zones. One region of increased clustering of seismicity here corresponds with the relocation of the 1978 Ms 7.0 earthquake (Avants et al., 2001).

T52E-07 1500h

Large Underthrusting Earthquakes Beneath the Nicoya Peninsula, Costa Rica

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Historically, the Nicoya Peninsula of Costa Rica has generated several large underthrusting earthquakes. The three most recent and well-recorded events occurred on: October 5, 1950 (Ms 7.7), August 23, 1978 (Ms 7.0), and March 25, 1990 (Mw 7.0). We investigate

the relationship of these events to current microseismicity, located in the recent CRSEIZE experiment (Newman et al., 2001), to obtain information about the seismic behavior of the thrust interface beneath the Nicoya Peninsula. Thousands of small local earthquakes, precisely located by the CRSEIZE experiment, define the geometry of the active plate interface in this region.

Each of the earthquakes investigated have a shallow, northeasterly dipping nodal plane consistent with underthrusting of the Cocos Plate beneath Costa Rica. However, the depth of 26 km for the 1978 event, determined by waveform modeling, places it below the thrust interface (if the location determined by Güendel, 1986 is assumed) suggesting it was an intraplate event within the subducted lithosphere. The 1978 event occurred as a doublet, followed about 12 minutes later by another Ms 7.0 event whose ISC location suggests an intraplate origin; no focal mechanism is available for this event. Using ISC arrival time data, we relocate both 1978 events and the 1950 event with respect to the 1990 earthquake, whose location was well constrained by the OVSICORI-UNA seismic network. Our relocations of both 1978 earthquakes are consistent with their occurrence on the plate interface, southeast and updip of the 1950 event. Two of the events investigated exhibited "doublet" like behavior with the 1950 event succeeded by and the 1990 event preceeded by relatively large sub-events. The "doublet" like behavior and clustering in the microseismicity in the vicinity of these large underthrusting events yields important information about stress concentrations and plate coupling across the seismogenic zone beneath the Nicoya Peninsula.

T52E-08 1535h

Rupture Dynamics of Subduction Zone Earthquakes in Light of Energy-to-Moment Ratios

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Subduction zone earthquakes can be broadly classified into 3 groups: (1) "normal" low angle thrust earthquakes at the plate interface; (2) very shallow earthquakes, which are often tsunami earthquakes; and (3) intra-plate earthquakes within the subducting slab. We determined the ratio of radiated energy (E_R) to seismic moment (M_0) of 22 large subduction zone events ($M_w >= 7.5$). The energy to moment ratios ($\tilde{e}$) of the events in group (1) are between $5x10^{-6}$ and $2x10^{-5}$, while the ratios of the events in group (2) are very low (between $6x10^{-7}$ and $2x10^{-6}$). The events in group (3) generally have larger ratios (between $2x10^{-5}$ and $1x10^{-4}$). We interpret the differences in the ratios of the three groups in terms of the differences in effective fracture energy in different seismogenic parts of the subduction zone. Using a simple model, we can write the ratio of the fracture energy to the radiated energy as

$$E_G/E_R = \frac{\Delta\sigma_s}{2\mu\tilde{e}} - 1,$$

where $\Delta\sigma_s$ is the static stress drop and μ is the rigidity. Using a global average value of $\Delta\sigma_s = 30 bars$, and $\mu = 3x10^{11} dyne/cm^2$, we find that the ratio E_G/E_R is between 1 and 4 for the "normal" subduction zone earthquakes (group (1)). For events in group (2), the ratio is at least 10 times larger, and for events in group (3) the ratio is very small (almost 0). The static stress drop, $\Delta\sigma_s$, may vary considerably among events and among the different groups; this could result in variations in the ratios of E_G/E_R. However, the overall trend is quite robust and suggests that the rupture dynamics in the different seismogenic parts of the subduction zone are significantly different. Intra-plate events (group (3)) are most "brittle" in their dynamic behavior whereas shallow tsunami earthquakes (group (2)) exhibit the least brittle behavior; "normal" thrust earthquakes have intermediate dynamic characteristics. Thus, broadband seismic observations of macroscopic parameters like M_0 and E_R provide useful constraints on the dynamics of large earthquakes.

T52E-09 1550h INVITED

The Evolution of the Decollement in the Nankai Trough Inferred from 3-D Seismic Reflection Data and ODP Leg 196 Drilling

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In 1999 we acquired a 3-D seismic reflection data volume to trace the evolution of decollement thrust zone from its initiation at the toe of the Nankai trough accretionary wedge down dip into the seismogenic zone. The 3-D seismic data were acquired on the R/V Ewing, and imaged an 8 x 80 km volume of the Nankai Trough accretionary wedge off the Muroto peninsula, which overlaps with ODP Leg 131, 190, and 196 drill sites.

The decollement and proto-decollement seismic reflections, with constraints from borehole physical property measurements, map physical properties of the fault zone from the deformation front into the seismogenic zone. A prominent reversed-polarity seismic reflection develops along the proto-decollement about 5 - 7 km seaward of the deformation front within the lower Shikoku Basin facies, 120 m below the boundary with the upper Shikoku Basin facies. This reflection extends beneath the wedge to Site 808, 3 km landward of the deformation front, where LWD data show that the reflection is caused by a decrease in density and seismic velocity at the base of the decollement corresponding to the contrast in porosity of the decollement (~28%) and the underconsolditated underthrust sediments (~50%). The interface forms within the bottom 3-4 m of the 19-m-thick decollement shear zone, implying that the decollement lies within the uppermost few meters of this underconsolidated and presumably overpressured section. The decollement reflection amplitude diminishes sharply landward from Site 808 beneath the accretionary wedge. Ten km landward of the wedge toe, the decollement reflection is a factor of 5 smaller than beneath Site 808. The reduction in amplitude indicates the underthrust section consolidates significantly to <30% with a loss of approximately 2/3 of the available pore fluid within the interval at the base of the decollement. However, fluid distribution is uneven, as 2-3 km wide patches of relatively high-amplitude polarity-reversed decollement reflections emerge along the decollement and extend to the updip limit of the seismogenic zone, 30+ km down dip from the deformation front. These patches of locally high-amplitude, polarity-reversed reflections are indicators of highly-pressured fluids caused by either delayed consolidation within segments of the fault, or pulses of fluids that dilate the fault zone as they migrating along it.

T52E-10 1605h

Out-of-Sequence Thrust and Normal Faults in the Rupture Zone of the 1944 Tonankai Earthquake

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We carried out a multichannel seismic reflection (MCS) survey to reveal structure of the central Nankai Trough margin, especially the 1944 Tonankai coseismic rupture zone, off east Kii Peninsula using R/V "Kairei" of the Japan Marine Science and Technology Center in May 2001. The MCS profile reveals a landward dipping, strong reflector with negative polarity in the forearc basin, likely cutting through the entire upper plate. The reflector appears to branch upward from the topmost reflector of the subducting oceanic basement, almost reaching seafloor just seaward the outer ridge. Where the reflector branches upward is apparently within the brittle rupture asperity with large coseismic slip (> 2 m) of the 1944 Tonankai earthquake, leading us to interpret this reflector as a splay fault, i.e., a sort of out-of-sequence thrust fault branching upward from master slip plane of recent megathrust earthquake (e.g., the 1944 Tonankai earthquake). This 30-km-long splay fault in sigmoid shape branches upward from the plate boundary at 10 km depth. This splay fault is also observed on another MCS profiles across the central Nankai Trough off east Kii, suggesting the almost ubiquitous presence of this splay fault dislocating the upper plate in the central Nankai margin. We propose that the interseismic shear stress may be relaxed in two ways at a megathrust earthquake, i.e., slips along the splay fault and seaward extension of the master slip of the plate boundary, which means that coseismic slip partitioning might occur around the updip end of the central Nankai seismogenic zone. Moreover, this splay fault may be tsunamigenic. The cover sequence of forearc basin shows several landward slightly-dipping bedding planes, suggesting substantial uplifting of the outer ridge. The MCS profile reveals several active normal faults just landward from the outer ridge, cutting down the dipping cover sequence and even the basement of the basin. It is possible that both the forearc basin and the outer ridge might suffer the coseismic uplift, and postseismic subsidence occurs at present. We believe that the active normal fault is an evidence for ongoing postseismic healing process in the forearc basin.

T52E-11 1620h INVITED

Splay Faults as Primary Targets for Drilling Within the Nankai Subduction Zone

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The Nankai subduction may be considered as an ideal case of fully and homogeneously locked subduction. Large earthquakes occur there on a quasi-periodic basis (100-150 yr.) and account for most of the subduction motion. It has been considered for many years as a prime target for investigations by drilling of the seismogenic zone. However, the important role played by subducting basement topography in the structuring of the Nankai wedge and subduction zone has only recently been realized. We propose that activation of splay thrusts is a mechanism by which subducting basement topography influences seismic activity in a decisive fashion and consider that these splay faults become primary drilling targets relatively easy to reach. As the geometrical asperity is impinging the accretionary wedge, it leaves a scar behind it in the form of an embayment. Decollement propagation restarts seaward of it at an accelerated rate. As the asperity is subducted below the backstop, one (or several) splay fault is formed and may propagate laterally beyond the geometrical asperity. From then on, a significant part of the subduction motion is diverted along the splay fault that is probably the true prolongation of the seismogenic zone to the seafloor. In this model, most of the motion is released along the splay fault during the earthquake and during the interseismic period, a significant part of it is slowly transferred to the seaward ductile decollement. Thus splay faults become very important targets for drilling as they can be reached with limited core length and as they have a decisive influence on the rupture distribution during large earthquakes and on the generation of tsunamis. In eastern Nankai, the impingement every two millions years or so of the wedge backstop by regularly spaced volcanic ridges associated with the Izu-Bonin arc activates splay faults with associated fluid seepage sites (Tokai Thrust and possibly Kodaiba Fault). Tokai thrust continues westward within the Kumano basin beyond the subducted ridge. In central Nankai, seamount groups along a now inactive spreading center also impinge the margin and are the likely cause for activation of splay faults. These appear to extend westward south of Tosa basin. Seismological and tsunami studies suggest that coseismic motion on these splay faults occurred during the 1946 Nankai-do subduction earthquake. Consequently, both zones appear as major drilling targets corresponding to a similar scientific rationale. We argue however that Eastern Nankai is logistically easier to address by drilling. We note further that the eastern target was not ruptured during the 1944 Tonankai earthquake and that consequently the events immediately preceding the rupture may be monitored within the instrumented hole.

T52E-12 1635h

Subduction of Oceanic Highs and Splay Faults in Eastern Nankai Subduction Zone

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The easternmost part of the Nankai accretionary complex (Tokai area) is presently underthrust by a large basement ridge going into subduction and known as the Paleo-Zenisu ridge. As a consequence, the upper margin has recorded a large finite compressional deformation with broad folding of the forearc basin as well as localized active faults known as Enshu fault, Kodaiba fault and Tokai thrust. These faults are located above the locked part of the subduction megathrust and are likely splay faults of the seismogenic zone.

In this presentation, we combine the existing geophysical data together with the most recent results of the French-Japanese "SFJ" seismic cruise to define the geometry of the Paleo-Zenisu indenter and of the splay faults. The Tokai thrust is the closest to the indenter. It also corresponds to the limit between the Plio-Quaternary accretionary wedge and the Miocene-to-Quaternary uplifted forearc basin domain. This structure is laterally continuous westward and follows the wedge/forearc limit. Enshu fault, the closest to the coast, has a right-lateral strike slip component and dies out westward in Kumano basin. It may thus in part result from shear partitioning in a locally oblique convergence setting. Kodaiba fault is now identified as an oblique thrust fault with a moderate dip angle and evidence for fast hanging wall uplift is found at the intersection with Tenryu canyon. Kodaiba is not laterally continuous but terminates westward in en-echelon fold system

We conclude that the initial structure of the Tokai margin was similar to that Kumano transect and that the current structure of the margin is the consequence of cyclic ridge subduction. We propose the deformation sequence during ridge subduction starts with a long wavelength folding of the whole forearc area and is followed by localization of the deformation along discrete faults and rupture within backstop. In this sequence, Kodaiba fault would be the most recent structure.

T52F MC: 135 Friday 1330h

Multidisciplinary Insights from Seismic Tomography, Mantle Dynamics, Geological Origins, and Evolution III *(joint with S, V, DI, MR)*

Presiding: **D Zhao,** Dept. of Earth Plantary Sciences**; K Hirose,** Tokyo Insitute of Techonology

T52F-01 1330h

Degree 16 model of S-wave heterogeneity in the upper mantle determined by the Direct Solution Method

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We determine degree 16 model of S-wave heterogeneity in the upper mantle by waveform inversion of long period surface wave data. We use the Direct Solution Method (DSM. Hara et al., [1991]) for theoretical calculations. Although the high accuracy of the DSM can improve the accuracy of earth models (Hara and Geller [2000]), the resolution of the model is still limited due to its heavy computational requirements (e.g., Hara and Geller [2000] obtained an degree 8 model of the upper mantle S-wave velocity). It is necessary to improve the DSM computational efficiency to raise the model resolution. Recently, Hara [2000] implemented the DSM codes on vector-parallel supercomputer to find that the improvement of@computational efficiency is almost proportional to the number of processing elements. In the present study, we apply these codes to analyses of surface wave data in the frequency band 2-4mHz. The upper mantle is divided into three layers (11-216 km, 216-421 km, and 421-671 km), and the lateral heterogeneity is expanded using spherical harmonics up to degree 16. Long wavelength features of this new model are similar to the model of Hara and Geller [2000]. There is a good correlation between low velocities and hot spot distributions in the shallow upper mantle (11-216 km). There are low velocities in the transition zone under some hot spots (e.g., south Pacific), which suggests that it is possible to trace temperature and/or chemical heterogeneities related to hot spots by surface wave studies.

T52F-02 1345h

3D upper mantle Q structure from waveform inversion and its interpretation

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We present a degree 8 model of attenuation in the upper mantle obtained by iterative inversion of three component long period seismic waveforms for elastic and anelastic structure. The main features of this model are stable and present interesting relations to corresponding elastic 3D tomographic models (obtained separately for SH and SV). In general, this model confirms the main features of our previous QR19 model, derived in a completely different manner and with lower resolution.

In the first 200-250 km of the upper mantle, we confirm the correlation of low Q with ridges and back arcs as well as high Q with the main shield regions. A feature not seen in SH, but present to some extent in the elastic SV model, is a zone of low Q spanning from Alaska to the south Pacific superswell. At greater depth and continuing into the transition zone, the correlation with tectonics and the low Q under Hawaii fade out, and the most prominent features of the Q model are two low Q minima centered in the Pacific and under Africa (the latter less well resolved). These low Q regions include most of the hotspots, correlate with low velocities in the elastic models, and, strikingly, are positioned above the two "superplumes" documented in the lowermost mantle from elastic tomography. This suggests a continuity in the rising currents associated with these superplumes up through the 670 km discontinuity and the upper mantle transition zone, and a strong thermal component to these plumes. When reaching the lithosphere, these currents are then deflected towards mid-ocean ridges. In particular, the presence of a low velocity region in the central Pacific in the SV model but not the SH model at depths around 200 km, associated with low Q supports the idea that the anisotropy previously documented in this region is related to a major upwelling which changes direction from vertical to horizontal in the uppermost mantle.

T52F-03 1400h

Observations of the Lehmann discontinuity and lower mantle reflectors using SS-precursors

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The upper mantle of the Earth is separated from the lower mantle by two globally confirmed discontinuities at 410 and 660 km depth. We performed a global search for additional mantle discontinuities by making use of regional stacks of precursors to the SS-phase. A bootstrap resampling algorithm is employed to determine robust reflectors (within the 95 % confidence level) and we have sought correlations with features in tomographic models, e.g. subduction- and plume-related features. These observations can be used as a probe for mantle composition and temperature.

The largest number of reflections comes from depths of 200-230 km which we associate with the Lehmann discontinuity. The global stacks show higher amplitudes for the Lehmann discontinuity beneath continental regions and much lower amplitudes beneath the oceans. The regional stacks show reflections where other techniques have shown a 220 km discontinuity, i.e. in the North American craton (Lehmann, 1959) and the Indonesian subduction zone (Revenaugh & Jordan, 1991). We also show new evidence for a Lehmann discontinuity beneath the oceans, where the depth and amplitude are much more variable than below the continents. There are also clear reflections from a depth range of 260-310 km, which correlate with observations of the X-discontinuity by previous investigators.

The stacks also show evidence for reflections from the lower mantle for a range of depths. We do not find one global lower mantle discontinuity, but local reflectors in certain regions. For example in the Indonesian subduction zone region these appear to confirm the 'mid mantle discontinuity' at 1050 km as suggested by Niu & Kawakatsu, 1997.

T52F-04 1415h

Evidence for a Regional Nature of the Lehmann Discontinuity

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The Lehmann (∼220 km) discontinuity is one of the elusive features of upper mantle structure. It is a sharp discontinuity in the PREM model, but it is one of the features of this model that is criticized most often. Also, 220 km does not correspond to any phase transformation predicted for common minerals of the upper mantle. There is little question that it is not a global feature, unless it has a very large topography, because it would be seen as a precursor in stacks of seismograms, such as those presented by Shearer (1990). Taking advantage of a large body of data gathered to study global topography of the transition zone discontinuities, we perform a global survey for the presence of the Lehmann discontinuity using ∼20,000 long-period, transverse component waveforms containing the *SS* phase and its precursors. We stack seismograms with reflection points within spherical caps of 10° radius. This data set is strongly sensitive to upper mantle reflectors and the coverage is more complete than in earlier studies. Our survey indicates that the Lehmann discontinuity is a regional feature that is observed under continents more than twice as often as it is observed under oceans. We observe significant variations in travel times and waveforms associated with this shallow mantle reflector, indicating its complexity and lateral depth variations. Little signal is detected on the continent-scale stacks of the *SS* precursors, which provides further evidence for the localized and variable nature of the Lehmann discontinuity. For example, the discontinuity is always detected in Eastern North America, but it is absent in the West. Also, its detection is more common in the stable part of Asia.

T52F-05 1430h

Density Structure of the Upper Mantle under North America

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We present a new high-resolution density model for the lithosphere and upper mantle of North America and analyse its geodynamic and tectonic implications. This model is based on an integrated analysis of gravity, seismic refraction, seismic tomography, drill-hole, and geological data. The thickness of sedimentary cover was determined from geological maps, and the average density-depth relationship was estimated for each specific basin from published data. The density model of the consolidated crust (including Moho variations) is derived from seismic determinations. By removing the effect of the crust we calculate the residual mantle gravity anomalies and the residual topography which are due to density inhomogeneities in the upper mantle. A joint analysis of these results with seismic tomography data (Van der Lee et al., 2000) leads to a construction of a 3D density model of the upper mantle under North America that is consistent with the residual gravity and produces the dynamic topography which is close to the residual one. The obtained density variations in the upper mantle under North America change significantly with depth. We conclude that they can not be explained solely by variations in temperature (Goes and Van der Lee, 2001) but also by compositional differences. Under Canadian Shield this difference is negative and is equal on the average to -$40 \pm 5 kg/m^3$ which corresponds to 1.2% depletion. The opposite compositional anomaly is found in the southern part of North America adjoining to Gulf of Mexico, it exceeds 30 kg/m^3. The origin of this anomaly is in dispute.

T52F-06 1445h

Insights into the tectonics of the British Isles from seismic tomography

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