Japan Geoscience Union Meeting 2011
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SSS028-01 Room:302 Time:May 26 08:30-08:45

Automatic arrival time picking compared to manual picking (2)

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Various types of seismic studies, including EEW systems, require automated programs for the accurate picking of P and S wave arrival times. The study on automatic picking was started in the late 1970 decade; however, even now, the accuracy is low and not suitable for detailed studies. We developed a new method of automatic picking, which is similar with the software used in computer chess games. The method defines an initial model of evaluation equation, which can select actual P and S wave arrival times among candidates by using values that show the characteristics of waveforms in time periods between candidates and about 100 unknown coefficients. By using a large number of waveform data together with manually picked P and S wave data, the unknown coefficients are determined such that the square of arrival time differences between manually picking and by the evaluation equation is minimized. It takes only 0.1 sec in the calculation of the evaluation equation for 10,000 events; very short computing times makes possible to determine many coefficients to decrease time difference. The method was applied to about 80,000 waveform data and results show that our new method can determine correct arrival times with an accuracy nearly same or slightly better than that of manual pickings. The method was also applied to the waveform data for AE observation in a South African mine.

Keywords: Automatic picking, P and S wave arrival times, Evaluation function, AE, real-time waveform data, Hypocenter location

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SSS028-02 Room:302 Time:May 26 08:45-09:00

High-resolution crustal stress field in the focal region of the Western Nagano Prefecture earthquake

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High-resolution crustal stress field was estimated in the focal region of the Western Nagano Prefecture earthquake, by a stress inversion of focal mechanisms. In the Western Nagano Prefecture region, microseismic activity continues for about 25 years after the 1984 Western Nagano Prefecture earthquake. A dense seismic array was operated in these 16 years and recorded more than 30000 earthquakes. By using these high quality data, stress heterogeneity along the mainshock fault and around the fault.

Keywords: intraplate earthquake, stress field, Western Nagano Prefecture earthquake, fault, focal mechanism, low velocity anomaly

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SSS028-03 Room:302 Time:May 26 09:00-09:15

Heterogeneous structures in the source region of the 1891 Nobi Earthquake based on a dense linear array

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We deployed a dense seismic array along the source faults of the 1981 Nobi-earthquake (the largest magnitude intraplate earthquake in Japan). The seismic array consisted of 98 temporary seismometers with spatial interval of about 1 km. We manually picked first arrival times of P and S-waves for local and intraslab earthquakes beneath the seismic array, based on JMA catalog. Then, we obtained a detailed velocity model along the source faults, applying the TomoDD-code. In addition, we calculated receiver functions using teleseismic waveforms recorded by stations equipped with 1 Hz seismometers within the array, applying the spectral division.

The depth of hypocenters gradually deepens from NW to SE. At NW edge, we found out a localized low velocity layer near the bottom of the seismogenic zone. This low velocity layer also gradually deepens toward SE. Most of earthquakes near the faults occur along the periphery of high velocity bodies. We identified a high-velocity gap at depths around 20 km beneath the source faults. Furthermore, the oceanic Moho of subducting Philippine Sea Plate is imaged around SE areas.

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SSS028-04 Room:302 Time:May 26 09:15-09:30

Seismic velocity structure between the Nobi earthquake fault system and the Fukui earthquake fault system

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1. Introduction

The 1891 Nobi earthquake is the largest inland earthquake in Japan. A lot of active fault segments run parallel or oblique mutually in NW-SE direction around the source area, and some of them were simultaneously ruptured in 80 km at the event. Since seismicity of the source area is still relatively high, we chose as a case study site to detect important factors of simultaneous rupture. We have carried out morphological, geological and geophysical surveys around the step-over between the two ruptured fault segments, Nukumi fault and Neodani fault since 2009. In this meeting, we present velocity structure around the boundary area of the Nobi earthquake fault system and the Fukui earthquake fault system based on the micro-earthquake observations performed in 2009 and 2010.

2. Seismic observation

In the first year, 26 temporal seismic stations were deployed around the Nukumi faults and half the north of the Neodani fault from June to November, 2009. In the second year, also 26 stations were deployed around the boundary area of the Nukumi fault and the Fukui earthquake fault system from May to November, 2010. Three dimensional velocity sensor LE-3Dlite and off-line recorder DAT-4 were settled at every station. The input data are continuously recorded at sampling frequency of 200Hz.

3. Tomographic inversion

In order to clear subsurface structure around the active faults, we carried out a tomographic inversion analysis using tomoDD. First, local earthquakes were manually picked from the continuous record and their hypocenters were located provisionally using a P wave velocity structural model of two horizontal layers (5.5km/s to 0-3km, and 6.0km/s to 3km-). Picking information at some surrounding permanent stations of JMA, NIED, and universities was also used in the analysis. Second, arrival time data of the 550 local earthquakes and 8 dynamite shots, and the other download picking information of 440 local earthquakes by permanent stations are used in the tomographic analysis. The absolute arrival times used in the tomography were about 25,000 for both P and S waves . The differential arrival times reaches about 90,000 for both P and S waves.

4. Velocity structure around the active faults

Low velocity zone are remarkable between the Nukumi fault and Ibigawa fault at the shallow part (z=0,3km). In contrast high velocity zones are found at both outsides of it. The high velocity zones are apart from each other about 10km at the surface, but they are closing at the deeper part (z=6,9km). As a result, the low velocity zone between them shows a prism body. Northern part of the Neodani fault and the Kurotsu fault which was ruptured in 1891 lies in the prism. Two outer faults may form a flower structure and a new fault is created in the center. The facts indicate that fault rupture is easy to propagate from the extension to a fault segment which is put in the low velocity zone between two parallel faults.

In contrast, E-W velocity bands are found around the boundary area of the Fukui earthquake fault system and the Nobi earthquake fault system at the deeper part (z=6,9km). High and low velocity zones are repeatedly appeared every 5 km in the band. This strike and distance is similar to the active faults over them. Although there seems to be a seismic zone from the Fukui earthquake fault system to the Nobi earthquake fault system, the result indicates the existence of subsurface geological structure across the zone.

Keywords: the 1891 Nobi earthquake, the 1948 Fukui earthquake, Seismic velocity structure, Active fault

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SSS028-05 Room:302 Time:May 26 09:30-09:45

Vertical crustal movement around the northern Itoigawa-Shizuoka Tectonic Line Fault Zone revealed by continuous GPS

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The Itoigawa-Shizuoka Tectonic Line (ISTL) delineates the western margin of northern Fossa Magna, and has experienced active deformation since the opening of Japan Sea. At present, ISTL is one of the most active faults in Japan. However, there has been no historical large earthquake along ISTL and fault models for future earthquakes along ISTL have large uncertainties. We established 11 continuous GPS sites during 1999-2000 in order to resolve detailed crustal deformation around ISTL, but only horizontal movements have been discussed so far because of the limitation in measurement accuracy. Here we processed the ten-year long GPS data and obtained precise vertical signals.

Characteristics of vertical crustal movements around northern ISTL can be summarized as follows. 1) The Hida Mountains are uplifting at a rate of 4-5 mm/yr. The uplift zone extends to the boundary between the Hida Mountains and the Matsumoto Basin. 2) The Matsumoto Basin is tilted eastward and the eastern end of the basin has a subsidence of 1-2 mm/year. 3) Vertical movement of the Ohmine belt located between the Eastern Matsumoto Basin Fault and the Otari-Nakayama Fault is negligible. 4) Folding area east of the Otarai-Nakayama Fault is uplifting at a rate of 1-2 mm/year. 5) No significant vertical motion in the Central Uplift Zone.

These features are consistent with geological/geomorphological features, implying that current crustal movement reflects tectonic motion in a much longer term. Noticeable contrast in the vertical movement across the East Matsumoto Basin Fault, together with the concentrated shortening, implies that inelastic processes such as deep fault creep contribute to the regional WNW-ESE contraction. In addition, we should take other factors such consolidation of the sedimentary basin, secondary faults, and active faulting into account in modeling crustal deformation.

Keywords: Itoigawa-Shizuoka Tectonic Line, GPS, crustal deformation, East Matsumoto Basin Fault, Fossa Magna, uplift

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SSS028-06 Room:302 Time:May 26 09:45-10:00

Stress accumulation mechanism in and around the Atotsugawa fault: Effect of crustal heterogeneity

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First, to estimate the stress field in and around the Atotsugawa fault with higher spatial resolution than previous report (Katsumata et al., 2010), we added focal mechanisms for very small earthquakes.

Second, to explain the estimated stress field, we constructed a fault model using commercial finite element code ABAQUS which allows us to incorporate non-linear viscoelasticity and crustal heterogeneity. Considering remarkable change in the crustal structure, as well seen in the Bouguer anomaly, across the Atotsugawa fault, we systematically elaborated the effect of crustal heterogeneity on the stress accumulation rate on the Atotsugawa fault.

Keywords: Atotsugawa Fault, crustal heterogeneity, focal mechanism, stress field, FEM

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SSS028-07 Room:302 Time:May 26 10:00-10:15

Internal Structure of the Median Tectonic Line, SW Japan revealed by a borehole core

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Property of fault zones are changed depend on the physical conditions, and influence fluid migration and the mechanical and seismogenic behaviours of the Earth's crust. The fault zone architecture has been evolved by the changing of the physical conditions during the exhumation, thus the analysis of that helps to improve our understandings of the variable fault behaviours at different conditions which are important to construct a pertinent model to predict the mechanical behaviour of the crust.

The Geological Survey of Japan, AIST (GSJ, AIST) recently constructed an integrated groundwater observatory close to the Median Tectonic Line (MTL) in the eastern Kii peninsula in Japan, which is called the Iitaka-Ako observatory. At the observatory, an observation borehole reached 600.0 m and encountered the MTL at a drilling depth of 473.9m. The MTL is the Japan's largest onshore exposed fault, has a long history of displacement under variable conditions.

The objective of this talk is to summarize the internal structure of the MTL based on the analysis of borehole at the Iitaka-Ako observatory. The followings were revealed.

(i) One of the bore holes penetrated the MTL (the boundary between the Ryoke granitoids and Sambagawa metamorphic rocks) at a drilling depth of 473.9 m.

(ii) Regression of locations and altitudes of 8 exposed outcrops and the depth where the borehole penetrated the MTL by least square technique yields fault plane with the attitude of N86^{o}E56^{o}N. The fault plane around the Iitaka-Ako observatory is almost perfect plane without large roughness.

(iii) Beneath the boundary between the Ryoke granitoids and Sambagawa metamorphic rocks, the Sambagawa metamorphic rocks shallower than 555 m are extensively fractured which can be considered the major strand of the MTL. With in the major strand of the MTL, the depth range between 474.5 m and 477.25 m can be considered the fault core, which corresponds to the thickness of 1.1 m. The X-ray diffraction analysis suggests that the deformation in these zones occurs around the temperature of approximately 150^{o}C.

(iv) Several mylonite zones are developed in the hanging wall of the MTL. The temperature conditions of the deformation are varied from 300^{o}C to 450^{o}C.

(v) Quartz grain size in the mylonite deformed under 300^{o}C is very fine, suggesting deformation under high differential stresses.

(vi) The mylonite zones were variably overprinted by later cataclastic deformation, and several stresses which caused the cataclastic deformation can be separated.

The fault rocks formed at different conditions were observed in the Iitaka-Ako core, which help to improve our understandings of variable fault behaviours. Based on the above mentioned results, the internal structure of MTL will be discussed.

Keywords: internal structures of fault zones, Median Tectonic Line, borehole cores, geophysical logging

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SSS028-08 Room:302 Time:May 26 10:15-10:30

Strain rate and flow stress estimation based on the field boundary between grain-size sensitive and insensitive creep re

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Continuous rock samples of granitic mylonite recovered from the GSJ Iitaka-Ako observatory (Mie Prefecture, Japan) that drilled the Ryoke granitoid (Hatai tonalite) and the Sambagawa pelitic schist, through the Median Tectonic Line would provide us the crucial information about the development of crustal shear zones. In the granitic mylonites very near the MTL, mechanism transition between grain-size-insensitive creep and grain-size-sensitive creep was observed in granitic mylonite deformed under the greenschist-facies condition, with the quartz grain size of ~3 micrometer that was measured by the image analysis using images obtained by SEM-EBSD mapping. Based on the relationship between flow stress and grain size of quartz calculated by flow laws of dislocation creep and grain-boundary sliding, strain rate and flow stress for mechanism switch between dislocation creep and diffusion creep occurred in the granitic mylonite are 10-10 s-1 and 700 MPa at 300 degree C, and 10-8 s-1 and 600 MPa at 400 degree C, respectively. The strain rate of the granitic mylonite is much higher than the surrounding metamorphic rocks by 3-5 orders of magnitude. It suggests that deformation of ductile lower crust may be localized in a narrow shear zone, rather than uniformly distributed. The displacement rates of the shear zone with thickness of 1 m calculated to be 30 mm/yr at strain rate of 10-9 s-1 and 300 mm/yr at 10-8 s-1; they are much faster than average slip rate of active faults and horizontal displacement rate estimated by continuous GPS array measurement, suggesting that either the shear zone should be localized less than 1 m or parameters used in this calculation should be revised.

Keywords: strain rate, differential stress, diffusion creep, dislocation creep, mylonite, inland earthquake

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SSS028-09 Room:302 Time:May 26 10:45-11:00

Detection of Shear Heating from the Sanbagawa Belt nearby the Median Tectonic Line by using Raman Spectral Analysis

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Recognition of shear heating has potential to help in estimating the shear stresses that operate on major faults when they move. Surface heat-flow and fission track thermochronology in the vicinity of the major San Andreas Fault show no clear evidence for major shear heating. This is commonly used to infer a much lower shear stress than that expected based on rock deformation experiments. The cause of this discrepancy between experiment and observation remains unresolved. The Median Tectonic Line (MTL) is the largest on-land fault of the Japanese Islands with a movement history from the Cretaceous to the present, and is a suitable candidate for studies of shear heating and to investigate whether a low degree of shear heating such as that associated with the San Andreas Fault is a general characteristic of regional long-lived faults. Within the Ryoke belt to the north of the MTL, a progressive younging of fission track ages towards the MTL suggests shear heating was important. However, the thermal structure in the Sanbagawa belt to the south of the MTL has not been determined and the detailed thermal structure around the fault is not known. Our study aims to fill these gaps in our knowledge by clarifying the peak temperature attained in the Sanbagawa belt.

A semi-continuous core passing through the MTL was recently drilled by AIST in the Kii peninsula. The availability of this core enables us to conduct detailed analyses in key samples close to the fault. To study the broader thermal structure, we also sampled on a kilometer scale and studied the regional structure using field mapping techniques. Pelitic rock is the main rock facies of the Sanbagawa belt in the study area. This pelite was metamorphosed at temperatures $< 400\ ^{o}$C and minerals suitable for typical Fe^{++}-Mg exchange thermometers are poorly developed. As an alternative way of estimating peak temperature, we used Raman spectral analysis of carbonaceous material. Results show a consistent regional temperature of 341 ^{o}C - 348 ^{o}C at distances between 400 m and 4 km from the MTL. There is a significant rise within 200 m from the MTL to temperatures of 362 ^{o}C - 408 ^{o}C. These results show no evidence for a heat-anomaly on km-scales to the south of the MTL, but do show a clear temperature increase near the MTL. The spatial association of the heat-anomaly with the fault implies shear heating, but the anomaly is only observed in a narrow zone close to the MTL.

To evaluate these results in terms of shear heating on the MTL, we compared them to the temperature distributions calculated using simple analytical solutions for one-dimensional conductive heat flow with a planer heat source. Results of calculations for single fault movements show a clear temperature increase in a narrow zone close to the fault ($<$ ˜100 m from the fault), but the duration times at high temperature nearby the fault are short ($<$ ˜100 years). In contrast, results of calculations for constant slip rates show that high temperatures can be achieved near the fault if sufficient time has elapsed: of the order of 0.5 million years since the onset of fault movements. However, in this case the associated thermal anomalies are broad and developed over distances of $>$ ˜10km from the fault.

The thermal data obtained around the MTL show the characteristics different from the San Andreas Fault, and suggest that the shear heating can be generated by movements of regional long-lived faults. The heat anomaly in the Sanbagawa belt nearby the MTL and the results of the thermal calculations suggest that not only the heat conduction but also the other mechanisms involved with the heat-transport of shear heating.

Keywords: shear heating, Median Tectonic Line, Sanbagawa belt, boring core, raman spectral analysis, carbonaceous material

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SSS028-10 Room:302 Time:May 26 11:00-11:15

Correlation stress history with mineral composition at small brittle faults in the borehole core penetrating the MTL

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The Median Tectonic Line (MTL), the largest on-land fault in Japan, has a long history of displacement, and the fault rocks deformed under variable conditions exist. The analysis of internal structure of the MTL, therefore, helps to improve our understandings of variable fault behavior depend on the physical conditions.

AIST drilled a borehole penetrating the MTL for predicting the Tonankai-Nankai Earthquake at Iitaka-Ako, Matsuzaka, Mie prefecture. The drilling length is 600m. It crosses MTL at the depth of 473.9m. Hangingwall of the MTL consists of the Ryoke-derived tonalitic mylonite and footwall of the MTL consists of fractured rocks derived from the Sambagawa metamorphic rocks.

The hangingwall has gone through the three kinds of stress pattern after the mylonitization. These are stresses which caused normal faultings, North-South compressive stress and East-West compressive stress (present stress pattern) in turn with time (Shigematsu et al., 2010).

In addition, based on the analysis of deformation structure and alteration minerals, prehnite was formed before the stresses which caused normal faultings and laumontite had been formed since the stresses which caused normal faultings until the present stress pattern and then has decomposed later on in the hangingwall (Fujimoto et al., 2010).

Here we will more precisely reconstruct the history of the condition of deformation and alteration in the hangingwall by especially advancing the analysis of the alteration minerals in Fujimoto et al. (2010).

We collected the fault material on the slip surfaces of the about 250 small brittle faults whose stress histories are already analyzed in the borehole core. And we analyzed mineral composition of those samples by X-ray diffraction.

We recognized the following characteristics

(a) The mineral composition is different between slip surface and wall rock though the mineral assemblage is almost same.

(b) Mineral composition of the slip surfaces reflect hydrothermal alteration controlled by the meso scale fracture systems.

(c) The stress history does not precisely correspond to the mineral composition on each slip surface. The mineral composition on slip surface may have been affected by later stage hydrothermal alteration.

We inferred the following correlations between stress history and mineral composition.

(A) Quartz is dominant on the slip surfaces formed under the stresses which caused normal faultings.

(B) Calcite is dominant and laumontite is present on the slip surfaces formed under the North-South compressive stress.

(C) Both quartz and calcite are dominant and laumontite is scarce on the slip surfaces formed under the East-West compressive stress (present stress pattern).

Mode of occurrences of minerals on the slip surface should be studied for father understanding.

Keywords: Median Tectonic Line, Fault, Borehole core, Stress history, Fault material, Mineral composition

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SSS028-11 Room:302 Time:May 26 11:15-11:30

High-speed deformation by pressure solution creep along fault zones in upper crust

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The author has studied exhumation tectonics of metamorphic rocks for a long time, and recently recognized that deformation processes and mechanisms in metamorphic rocks during exhumation into upper crustal levels across the brittle-ductile transition zone provide us with clues to unravel those of inland earthquakes. For example, the Sambagawa metamorphic rocks, southwest Japan experienced pervasive normal faulting under nearly arc-normal extension at D2-phase, which occurred during the exhumation stage when they were elevated to upper crustal levels across the brittle-ductile transition zone. These normal faults formed at D2-phase are characterized by quartz sclikenfibre on fault plane, the displacement rate along which was perhaps controlled by pressure solution creep, and hence not accelerated to generate earthquakes (i.e. stable sliding). Other microstructures such as shear bands defined by alignment newly grown muscovite and chlorite, strain fringe with large aspect ratios, random c-axis fabric in quartz aggregates, etc. all indicate that the rate of pressure solution creep was fairly high.

In fact, the brittle strength shown in crustal strength profile so far constructed is that needed to generate earthquakes. However, while this critical differential stress only occurs once per a few thousand years at the time of earthquake in seismogenic fault zones, the stress during inter-seismic periods is far below this value. It has been considered that pressure solution creep occurs at such low differential stress conditions. Then, the point of discussion is how fast pressure solution creep or reaction-controlled creep occurs under these conditions in nature. If pressure solution proceeds so fast in fault zones, the differential stresses cannot be elevated to generate earthquakes. In reality, the structure of seismogenic fault zones is heterogeneous, which consist of very fine-grained mature fault rocks with numerous microfaults defined by development of aligned muscovite and chlorite (i.e. phyllosilicates), and relatively undeformed coarse-grained protolith not metamorphosed and deformed extensively. In these cases, while grain-size sensitive pressure solution creep occurs at higher rate in the former rocks, also assisted by a low coefficient of internal friction in phyllosilicate minerals (e.g., Bos and Spiers, 2002), stress becomes built up, leading to the generation of earthquakes in the latter rocks. This process is repeated, which explains the repetition of inland earthquakes. Since the undeformed rocks in fault zones can be correlated with asperities in subduction zones, this model can be called 'asperity model' for generation of inland earthquake (e.g. Jefferies et al., 2008).

Keywords: pressure solution creep, fault zones, repetition of inland earthquakes, strength profile of the continental crust, reaction softening, asperity

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SSS028-12 Room:302 Time:May 26 11:30-11:45

Rheology profile across the Northeastern Japan

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Recent seismological and geodetic observations have shown the current lithospheric deformation of the northeastern Japan arc (e.g., Hasegawa et al., 2005). These observations have shown a significant localization of GPS strains and concentration of shallow microseismicity along the Ou Backbone Range by the presence of hot upwelling flow including partial melts and water from mantle wedge beneath the volcanic front. Furthermore, the number of reverse slip earthquakes have been generated along steep-dipping reverse faults implies the reactivation of pre-existing faults under the presence of overpressured fluids (Sibson, 2009). However, despite close distributions between the presence of fluids (water and melt) and reactivated fault systems on recent earthquakes, the effects of fluids and pre-existing fault systems on the present-day lithospheric deformation and earthquake generation have not been quantitatively evaluated yet.

In order to predict the present-day lithospheric strengths across the NE Japan, I construct two dimensional strength profiles using the petrological model and geophysical observations for NE Japan combined with recent development in rock mechanics. The calculated strength profiles are compared with the distribution of microseismicity and geodetic strain field in the NE Japan. Based on the profile, I discuss the possible roles of fluids and pre-existing fault systems on fault reactivation.

The lithospheric strengths are calculated using frictional and ductile constitutive laws as a function of temperature, pressure and strain rates of the lithosphere. A petrological model of the NE Japan based on the laboratory measurement of seismic velocity by Nishimoto et al (2005) was adopted: granite for the upper crust, hornblende gabbro for the lower crust, and spinel lherzolite for the upper mantle. The geodetically determined horizontal east-west strain rate of about 10^{-7}/yr (Miura et al., 2004) was used to calculate the lithospheric strengths along the seismic profile across the Northen Honshu, Japan by Iwasaki et al. (2001).

The calculated strength profiles explain patterns of present-day geodetic strain accumulation and shallow seismicity along the Ou Backbone Range. Laboratory derived flow laws also reproduce the presence of weak zones by mechanisms likely operated in the lithosphere (e.g., partial melting and shear zone development). The strain localization into weak zones efficiently accumulates elastic strains at the base of upper seismogenic faults locked during interseismic periods (e.g. Ando and Okuyama, 2010). This may result in the reactivation of pre-existing fault systems in the NE Japan.

Keywords: Northeastern Japan, rheology, strength profile, earthquake, rock mechanics

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SSS028-13 Room:302 Time:May 26 11:45-12:00

Modeling fault development and mountain building along the Backbone range, NE Japan

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In northeastern Japan, many intraplate earthquakes occur on preexisting normal faults that are reactivated as reverse faults during shortening deformation (Sato, 1994). Stress-concentration processes, caused by the presence of heterogeneous rheological structures, are important for the reactivation of particular faults. It is acknowledged that the presence of aqueous fluids weakens the crustal rock beneath the Ou Backbone range to a greater extent than that in the surrounding area; this leads to shortening deformation in the lower crust beneath the range, which in turn induces the development of faults in the upper crust (e.g., Hasegawa et al., 2003). Okada et al. (2010) found a distinct low-velocity region below the focal area of the 2008 Iwate-Miyagi inland earthquake and suggested that the crustal fluids were related to the occurrence of this earthquake. A crustal thermal structure also affects the generation process of inland earthquakes. Yoshida et al. (2005) pointed out that crustal thermal structures have been affected by intensive magma intrusions to form large magma storages beneath the late Miocene to Pliocene calderas. To model fault development and mountain building in northeastern Japan, we need to consider crustal thermal structures, the presence of aqueous fluids, and preexisting weak faults.

We model fault development and mountain building all over northeastern Japan by considering viscoelasticity and elastoplasticity using a finite element code (Shibazaki et al., 2008). Recently, dense geothermal observations were carried out using Hi-net boreholes (Matsumoto, 2007). As a first step, we consider a geothermal structure based on Hi-net geothermal observations (Matsumoto, 2007) and the geothermal gradient data provided by Tanaka et al. (2004). On the basis of the rheological model developed by Muto (2010), we consider power-law creep for three layers: the upper crust (wet quartzite), the lower crust (wet anorthite), and the uppermost mantle (wet olivine). We also set the frictional angle to 15 degree. By giving an E-W contraction velocity of 0.2 cm/year, we examine the manner in which faults develop and mountain building occurs. Numerical results show that east- and west-dipping reverse faults develop in the high thermal gradient regions, and mountains that correspond to the Ou Backbone range are built up. In some areas, simulated fault geometry is not consistent with the observed fault geometry. For example, the strain concentration zone in the northern Miyagi prefecture cannot be reproduced in the model. To model the strain concentration zone in this region, the effects of water on the model of crustal deformation should be taken into account. We report the numerical results considering the non-uniform distribution of water fugacity and frictional strength.

Keywords: modeling, Ou Backbone range, mountain building, fault development, thermal structure, rheology

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SSS028-P01 Room:Convention Hall Time:May 26 14:00-16:30

Detailed seismic activity beneath the Nikko-Ashio area revealed by a tomographic analysis

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The Nikko-Ashio area, the northwestern part of Tochigi prefecture, is one of the most seismically active regions in Japan. Tectonic background in the region is dominated by the Pacific plate subducting westward from the Japan Trench. The area is located on the southeast end of the volcanic front expanding from the Tohoku to the Kanto. Active volcanoes such as Mt. Shirane and Mt. Nantai and also active faults such as the Uchinokomori fault are in the region. A large amount of shallow earthquakes about 6,000 ˜ 8,000 a year have been observed around active faults by the routine observations of the Earthquake Research Institute (ERI). The specific characteristics of the activity are as follows: 1. Earthquakes are mainly located in two regions. 2. Earthquakes separate into clusters. 3. Most earthquakes occur within a depth of 15 km. 4. The distribution tends to shallower toward Mt. Sirane. 5. Obvious SxS and SxP phases reflected from a crustal discontinuity are in the seismograms. 6. Deep low frequency earthquakes at depths of 20 to 40 km occur beneath the region.

Recently, many researchers have investigated what factors cause inland crustal earthquakes. Understanding of the Nikko-Ashio earthquakes will provide information concerning the construction of solutions.

To now we conducted time series analyses and travel time analyses for Nikko-Ashio data. We have obtained some information concerning velocity structures and seismic distribution..Low-frequency earthquakes have occurred about one a month, but sometimes more than dozens of them occur at a time. After that, shallow earthquakes obviously increase. From a tomographic study we have found that low-frequency earthquakes occur at the edge of high Vp/Vs areas and high Vp/Vs, low Vp and low Vs areas spread widely at depths of 20 to 30 km. We interpret that low-frequency earthquakes occur as the results of ascending magma flow and intermittent rapid magma flow causes many low-frequency earthquakes at a time. Upwelling magma flow accumulates at a depth of ˜20 km and the dehydration from the magma weaken the strength of the crust and causes shallow earthquakes.

In this report, we investigate precise earthquake distribution to obtain an improved understanding of these systems connected with magma or fluid. In the seismograms, there are many similar earthquakes. We adopt tomoDD inversion method to the travel time data with those wave correlation data during the period from April, 2002 to December, 2009.

Keywords: seismic distribution, low frequency earthquake, magma, fluid, velocity structure

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Migration of elements accompanied by the development of cataclasites in borehole penetrating the Median Tectonic Line

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Along the MTL which bounds the Ryoke shear zone and Sanbagawa belts the deformation was localized in the Ryoke shear zone with the decrease in the temperature. As a result, various fault rocks from mylonite to cataclasite were developed in the Ryoke shear zone. In the present study, the changes in volume and the element change were measured by the X-ray fluorescent analysis for the drilled core samples form the Iitaka Akou site. The drilling was conducted down to the Sanbagawa shear zone, 600m in total length. The fault rock samples used for the chemical analyses are from the drilling cores of 317m to 473m in depth. Hence, these samples all belongs to the Ryoke belt, and a host rock of the fault rock is tonalite. All the rocks experienced plastic deformation and became mylonite. Rocks suffered cataclasis as temperature decreased. To classify them by the degree of cataclasis, naked eye and thin section observations were conducted. As a result, the fault rocks were classified into four groups by the difference of the degree of cataclasis (nearly undeformed protolith, weakly deformed fault rocks, intermediately deformed fault rocks, strongly deformed fault rocks 'phyllonite'). Whole rock chemical compositions were analyzed by the X-ray fluorescent analysis to clarify the change in volume and chemical elements of these fault rocks, which were examined by the isocon method (Grant, 1986). In the present study, Al was used as an immobile element in fault rocks. Assuming that there was no density change of the fault rocks, the volume change can be estimated by the following equation. $dV=[(1/S)-1]*100$, where S is a slope of the straight line that connects the origin of isocon diagram with the plot of an immobile element. The element fluctuation rate can be calculated by the following equation for the change of each element. (Shikazono et al, 2007). Element fluctuation rate = (Elf/Alf)/ (Elh/Alh), where El is an arbitrary element, Al is an immobile element, and f and h are fault rocks and rocks of comparison, respectively.

The analyses by the isocon method were conducted for three kinds of combination. 'nearly undeformed tonalite and weakly deformed fault rocks', 'weakly deformed fault rocks and intermediately deformed fault rock', and 'weakly deformed fault rocks and strongly deformed fault rocks'. In the combination of 'nearly undeformed tonalite' and 'weakly deformed fault rocks', volume increases by 29.8 percent. Moreover, for the change of the major elements, K_2O (3.78), LOI (1.49), SiO_2 (1.46), Na_2O (1.28) increased, while TiO_2 (0.30), MgO (0.33), P_2O_5 (0.36), FeO+Fe_2O_3 (0.50), MnO (0.55), CaO (0.63) decreased. In the combination of 'weakly deformed fault rock' and 'intermediately deformed fault rocks', Volume decreases by 7.6 percent. Moreover, for the change of the major elements, TiO_2 (3.82), MgO (3.19), P_2O_5 (2.56), MnO (2.01), FeO+Fe_2O_3 (1.90), CaO (1.74), LOI (1.31) increased, while K_2O (0.76), Na_2O (0.80), SiO_2 (0.80) decreased. In the combination of 'weakly deformed fault rocks' and 'strongly deformed fault rocks', the volume decreased by 22.8 percent. Moreover, for the change of the major elements, MgO (8.76), TiO_2 (2.81), CaO (2.51), FeO+Fe_2O_3 (2.44), MnO (2.34), LOI (2.00), P_2O_5 (1.89) increased, and K_2O (0.60), Na_2O (0.56), SiO_2 (0.50) decreased. It is noted that the increase and decrease in the major element change show an opposite sense for 'nearly undeformed tonalite and weakly deformed fault rocks' and the other two combinations. The formation of new minerals correlated with the element change in the fault rocks is as follows. In the combination of 'nearly undeformed tonalite and weakly deformed fault rocks', an increase of K_2O corresponds to the formation of the muscovite and an increase of SiO_2 corresponds to the precipitation of quartz. In the other two combination an increase of CaO corresponds to the formation of calcite, and an increase of MgO and FeO+Fe_2O_3 corresponds to an increase of chlorite.

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Development of intrafolial folds at deeper extension of seismogenic fault

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It has been considered that the main ruptures of large inland earthquakes start in the brittle-plastic transition zone, as their hypocenters are generally located in the deepest region of the seismogenic zone. This suggests the significance of plastic flow in the brittle-plastic transition zone for the generation of large inland earthquakes. The Hatagawa Fault Zone (HFZ) in the north-eastern Japan consists of various kinds of fault rocks such as cataclasite, pseudotachylyte and mylonite, indicating the HFZ were formed under brittle-plastic transition zone.

We found intrafolial folds within the granitic ultramylonite in the HFZ. Intrafolial folds in the ultramylonite are different from other intrafolial folds grew in sedimentary or metamorphic rocks, because the observed intrafolial folds are developed in initially non-foliated granitic rocks. Fukudome (1986) proposed that intrafolial folds were developed by Kelvin-Helmholtz instability due to strain rate differences across the interface between foliations. Such plastic instability occurs at deeper extension of seismogenic fault may cause significant stress accumulation to upper seismogenic fault locked during interseismic period.

We analyze the quartz LPO and grain size, using SEM-EBSD analysis, and estimate the deformation condition. We explain the formation mechanism of the intrafolial folds that causes stress concentration in seismogenic faults.

Intrafolial folds are observed on the plane normal to the foliation and parallel to the lineation (XZ thin sections) of the ultramylonite. The folds consist of monomineralic recrystallized quartz aggregates. The folds show asymmetric profiles and wavelength are below 1cm order. The wavelength / thickness ratio is 1.2 - 4.5. The folded quartz aggregates have LPO, indicating that quartz aggregates were deformed by dislocation creep. On the other hand, matrix consists of fine-grained mixtures of quartz, feldspar and mica without significant LPO, indicating that matrix was deformed by diffusion creep.

EBSD analysis clarified that the LPO pattern of quartz in the folded part is parallel to Y of the strain ellipsoid (Ymax). The average grain size measured by EBSD orientation maps is in the range of 6.32 +/- 3.86 - 14.27 +/- 6.67 micrometers. Stipp and Tullis (2003)'s piezometer predicts differential stresses of 81 - 154 MPa. Presence of syndeformational hornblende and Ymax LPO indicate that the ultramylonite was formed at a temperature of 450 - 500C. Strain rates of folded quartz layer are estimated on the order of 10^{-12} and 10^{-10}/s, using Hirth et al. (2001)'s quartzite flow law. The strain rate folded quartz layer is 5 orders faster than current east-west contraction strain rate estimated from GPS observations in the NE Japan (10^{-15}/s: Miura et al., 2004). Because the intrafolial folds are developed by the difference in strain rates (Fukudome, 1986), the fine-grained matrix might be deformed at higher strain rates than the competent quartz layers. This implies that the strain concentration in deeper extension of seismogenic faults results in stress accumulation to upper faults locked during interseismic period.

Keywords: intrafolial fold, plastic instability, ultramylonite, Hatagawa Fault Zone, inland earthquake