

earthquake, we studied the low-P/T metamorphic rocks in the Ryoke belt, southwest Japan. The Ryoke belt in the Iwakuni-Yanai area is underlain by Jurassic accretionary complex and their metamorphosed equivalents. They were intruded by Cretaceous granitic rocks. Five metamorphic zones can be defined by mineral assemblages of pelitic rocks as a regional metamorphism before the intrusion; chlorite, chlorite-biotite, biotite, cordierite and sillimanite zones from north to south (Ikeda, 1993). Silicified rocks have been found in pelitic schist of the biotite zone and northernmost part of the cordierite zone. The pelitic schist is dark in color but silicification turned it to be pale gray or milky white. Silicified pelitic schist is mainly composed of fine-grained quartz and minor muscovite and biotite. The silicified pelitic schist forms layers or lenticular bodies several to fifty meters in thickness. The boundary between silicified rock layer and underlying pelitic schist is fairly distinct but that between the overlying pelitic schist is gradual. Quartz veins crossing high angles with schistosity were preferentially developed in the silicified rock layers, while schistosity-parallel quartz veins, which underwent plastic flow, were observed in the pelitic schist. An echelon quartz vein and fishnet-like quartz veins are characteristic of silicified rock layers. This mode of occurrence of quartz veins indicates competence of silicified rock layers relative to pelitic schist. Rock boundary with high competence contrast is probably a good reflector of seismic waves. Bright-layer reflections would arise from silicified rock layers if those are distributed in the deep crust to a considerable extent.

T31F-0901 0830h POSTER

Revising the Triassic Unroofing History of the Qinling-Dabie Collisional Orogenic Belt: New Detrital Zircon Provenance Data from the Songpan-Ganzi Complex Turbidites, West-Central China

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Approximately 300 new U-Pb SHRIMP ages were obtained from detrital zircons recovered from six samples of the Songpan-Ganzi Complex (SGC), a succession of turbidites over 10 km thick covering an area of 220,000 km² in the Sichuan province of west-central China. Situated 2000 km along structural strike of the Late Triassic-Late Jurassic Qinling-Dabie orogen, a collisional belt produced by the suturing of the North China block (NCB) with the South China block (SCB), the SGC exists as the prime, yet unproven, candidate for the ultimate sink of Qinling-Dabie derived detritus. Age spectra recorded by two samples from the north-eastern zone and two samples from the central zones of the SGC record an initial source of early Paleozoic rocks of the SCB during the late Middle Triassic/early Late Triassic; by the late Late Triassic zircon age spectra are dominated by a 1900 Ma population derived from the NCB. This data represents the most statistically robust zircon provenance data set and contradicts a previous interpretation of another data set of less than 50 U-Pb ages of detrital zircon crystals recovered from two Middle Triassic samples and one Upper Triassic sample of the central zone of the SGC that were interpreted to indicate a provenance shift from the mid-Proterozoic rocks of the NCB to a dominantly 750-850 Ma source derived from rocks of the SCB. Age spectra from samples collected from the western zone of the SGC indicate a dominantly Proterozoic source with no Triassic grains, which is inconsistent with the previous interpretation that the western SGC turbidites were sourced by a contemporaneous volcanic arc. Geobarometric data indicate that ultrahigh pressure metamorphic rocks exposed within the Qinling-Dabie orogen were at or near the surface by 200-230 Ma; however, the SGC as a whole does not contain a large population of Late Triassic zircons that would indicate a Qinling-Dabie orogen source. Instead, the abundant Early and Late Proterozoic grains suggest the SGC records erosion of the SCB, perhaps prior to collision of the SCB with the NCB, followed by unroofing of more than 100 km of NCB crust to expose the Qinling-Dabie UHP rocks as suturing of the NCB and SCB progressed.

T31G MCC: 3005 Wednesday 1020h

Heat Sources in the Core (joint with GP, V, MR, DI)

Presiding: G Steinle-Neumann, Bayerisches Geoinstitut, University Bayreuth; B Buffett, University of Chicago

T31G-01 1020h INVITED

Radiogenic Heat Production in the Core?

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Radiogenic heat production in the Earth is dominated by three elements: K, Th and U, which mainly reside in the Earth's mantle and crust. The global budget is determined from the fact that Th and U are both refractory. Thus, it is believed that the Th/U ratio of the bulk Earth must be identical to those of chondritic meteorites. In contrast, K is a volatile element, but like Th and U is lithophile and incompatible. Relative to CI chondrites (K/U about 70,000), K is depleted by a factor of 6-7 in the Bulk Silicate Earth (BSE) due to volatility. New determinations of the chondritic Th/U ratio provide a value of 3.6, which may be taken to represent the bulk Earth Th/U ratio. The Th/U ratio (BSE) of 4.2-4.3 is determined by regression from lead isotope systematics. The discrepancy between the inferred bulk Earth and BSE Th/U ratios can be taken to imply that U is partially siderophile in the Earth, an observation that requires that D(U)= 0.3 between metal and silicate. The implied amount of U present in the core is sufficient to provide about 2-3 TW of power for the geodynamo. The presence of a uranium heat source significantly affects geophysical estimates of the timing of inner core crystallization. Recent Os isotope data imply that several plume sources have interacted with the outer core at the CMB. If this is correct, the high Pt/Os ratio inferred for the outer core would be most efficacious at explaining the observed Os isotope ratios if the inner core crystallized prior to 3.5 Ga. Such an early age of the inner core is not possible if heat loss at the CMB is dominated exclusively by latent heat release, but requires an additional source of radiogenic heating. It should be noted that most highly siderophile elements are siderophile at 1 atm conditions. However, many lithophile elements (V, Cr, Mn) become more siderophile at higher P and T. The mineral constituents of iron meteorites are notably lacking in U and Th, requiring that if U is present in the Earth's core it must change its metal-silicate partitioning at high P-T. While U is a prospective heat source for the Earth's core, resolution of the issue will require high P-T partitioning data for U and Th. Geophysical treatment of the crystallization rate of the inner core should include a discussion of the effect of radiogenic contribution to core heat production from U.

T31G-02 1040h INVITED

A Radioactive Heat Source in Planetary Cores: Experimental Evidence for Potassium

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The idea and the extent to which potassium is a radioactive heat source in the Earth's core has been highly controversial for the past thirty years because of ambiguous and contradictory experimental results, presumably due to unsuspected experimental difficulties. We present here results of studies free of such difficulties to show conclusively that K is soluble in Fe-S melts. In synthetic systems composed of K-silicate, Fe-metal, and FeS, potassium is readily enters the Fe-S melt at 2 GPa and magmatic temperatures, at fO_2

1.5 log units below the iron-wustite (IW) buffer. The data show a precise loglinear relationship between the partition coefficient D_K (concentration of K in sulfide/concentration of K in silicate) and inverse temperature, indicating that the solubility of K in the sulfide melt shows a strong positive correlation with temperature (T). If the Earth's core formed by segregation of metallic liquids in the Fe-FeS system, these observations suggests the presence of a significant amount of potassium in the core with consequent radiogenic heat production. The effects of pressure and composition on the partitioning of K in to Fe-S melt are not well constrained at this time. Our preliminary data show no effect of pressure in the limited range of our experiments but a significant effect of silicate melt composition. Until the effects of these parameters are defined better, only a heuristic estimate of the core radiogenic heat production is possible. For a range of 3000-4000 K core mantle equilibration temperature, the K content of the core is 60-130 ppm with a present-day heat production at $0.4 - 0.8 \times 10^{12}$ Watts and exponentially more in the past. A similar analysis suggests the radioactive heat production in Mars core to be 3×10^{10} Watts. This additional heat source in the cores of Earth and Mars has major implications for a number of global processes and the early history of these planets. Among these are, the early but now extinct global magnetic field of Mars, the longevity of 3.5 b.y. old terrestrial magnetic field, the age of the Earth's inner core, and the internal dynamics of the solid planet.

T31G-03 1100h INVITED

Quantum theory and high-pressure experiments on iron-potassium alloying: Radioactivity in the Earth's Core?

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Ab-initio quantum mechanical calculations support experimental evidence that several percent potassium (K) can be alloyed into iron (Fe) at high pressure, suggesting that K may have been incorporated into the iron-rich core during and after core segregation. This alloying process is of great importance to the thermal state and history of Earth's deep interior as radioactive decay of ⁴⁰K could be an important source of energy for the geodynamo and mantle dynamics. To test the possibility of K substitution into an ϵ -Fe unit cell, we performed density-functional based ab-initio calculations, with the projector augmented wave method as implemented in the Vienna ab-initio simulation package (VASP), of Fe supercells of various sizes in which K is substituted. In agreement with previous high-pressure diamond-anvil cell experiments we find that substitutional incorporation of K into ϵ -Fe causes the hexagonal close pack (hcp) structure to expand by an amount depending nonlinearly on pressure and concentration, with 3 atomic% substitution causing about 2% volume expansion at 35 GPa. We have used these results to analyze the amount of K that is alloyed into hcp ϵ -Fe found in experiments. Overall, these findings show that it is possible to sequester more than 0.1 atomic% (700 ppm by weight) of K into the Fe-based alloy of the Earth's core, which would provide upwards of 4.5 TW across the core-mantle boundary.

T31G-04 1120h INVITED

Thermal and Magnetic Evolution of the Earth's Core

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The magnetic field of the Earth is generated by convection in the liquid core and energy necessary for this process comes from the cooling of the core which provide several buoyancy sources. The thermodynamics of this system is used to relate the ohmic dissipation in the core to all energy sources and to model the thermal evolution of the core. If the same dissipation is maintained just before the onset of inner core crystallization, and the associated compositional convection, as at present, a much larger heat flow at the core mantle boundary (CMB) is necessary which, if extrapolated backward, may require a very high initial temperature. Two solutions to that problem are studied: either the ohmic dissipation was smaller then, which could be maintained with the same heat flow as at present or an important radioactivity is present in the core. The presence of radioactivity in the core makes the inner core only a few hundred million years (Ma)

older than non-radioactive cases with the same dissipation, because the low efficiency of radioactive heating requires a much larger heat flow at the core mantle boundary. Although the age of the inner core is controlled by the heat flow at the CMB, the ohmic dissipation to be maintained is the constraint that makes it low.

T31G-05 1140h

The power requirement of the geodynamo from scaling Joule dissipation in numerical models

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In order to constrain models of the thermal evolution of the core, the nucleation time of the inner core and possible requirements for core heat sources, the power needed to maintain the geomagnetic field against Joule dissipation must be known. Here I use results from a large number of convection-driven spherical shell MHD dynamo models to derive a systematic scaling of the magnetic decay time τ , defined as the time-average of magnetic energy over Joule dissipation. The magnetic Reynolds number Rm covers the range between 50 and 1000, Ekman numbers are between 3×10^{-4} and 10^{-5} , and magnetic Prandtl numbers Pm between 0.25 and 3. The results are fitted fairly well by a simple relation of the form $\tau \sim Rm^{-1}$. A weak dependence on the magnetic Prandtl number may exist and a two-parameter fit of the form $\tau \sim Rm^{-1} Pm^{1/6}$ reduces the scatter somewhat. I use a ratio of ≈ 7 between the mean field strength inside the fluid shell and at its surface, taken from a model with a particularly Earth-like field, to estimate the magnetic energy density in the core as $3J/m^3$. For $Rm = 500$ the simple scaling of magnetic decay time predicts a Joule dissipation of $3 \times 10^{11} W$ in the core. When a dependence on the magnetic Prandtl number is assumed, this figure rises to $3 \times 10^{12} W$. While the former value can be easily accommodated in the energy budget of the core, the second one puts severe constraints on its thermal history and energetics.

T31G-06 1155h

Numerical and Parameterized Modeling of the Earth's Thermal History: Effects of Heat Producing Elements in the Core

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Thermal convection in the Earth's mantle regulates the rate at which heat is lost from the Earth's interior. Factors affecting the vigor of that convection, such as the viscosity of the mantle and barriers to convection such as the 660-km endothermic phase transition, as well as the rate of radioactive heat generation within the planet determine the rate at which the Earth is cooling. In this presentation, we will describe a suite of simulations of the Earth's thermal history using both parameterized and numerical (fluid-dynamical) modeling of convection in the Earth's mantle. The core is modeled, in both cases, as a heat reservoir which is used to set the temperature boundary condition at the CMB for the numerical model. We investigate the effects of varying the concentration of heat producing radioactive elements in the core by varying the degree of internal heating in this region. We find that the inclusion of modest amounts of heat producing elements in the core results in simulations that fit modern constraints on temperature in the mantle as well as surface heat flow while geochemically derived mantle radioactive abundances of heat producing elements are used.

T31G-07 1210h

The Effects of Radiogenic Heating in Geodynamo Simulation

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Recent studies have suggested that potassium-40 may be present in the Earth's fluid outer core. The presence or absence of this radiogenic isotope may have an effect on magnetic field generation. This study examines the consequences of radiogenic heating on the character of a simulated magnetic field. The Glatzmaier-Roberts geodynamo model is used to test the effect of different levels of radiogenic heating with both homogeneous and tomographic core mantle boundary (CMB) heat flux conditions. Zero to fifty percent of the simulated CMB heat flux is generated by radiogenic heating. The total heat flow through the CMB is prescribed to be the same total amount in every case. Preliminary results show variation in the velocity, magnetic field, and temperature structures in the different cases.

T31H MCC: 3007 Wednesday 1020h

Izu-Bonin-Mariana Arc Processes and Progress II (joint with S, V)

Presiding: S Klemperer, Stanford University; J Gill, University of California, Santa Cruz

T31H-01 1020h

Marine Magnetotelluric Experiment for the Mariana Subduction System

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A marine magnetotelluric (MT) experiment was carried out in the central Mariana area from 2001 to 2002 to elucidate electrical structure of the subduction-arc back arc system. The electrical conductivity is mainly subject to temperature, partial melt, and volatiles such as water in the mantle. 10 ocean bottom electromagnetometers (OBEMs) were deployed along the line crossing the central Mariana trough during the cruise YK01-11 in October 2001. This OBEM array covers from the Pacific plate to Parece-Vela basin through Mariana trough. 5 of them were successfully recovered during the cruise using R/V M. Ewing in April 2002 and during the cruise KR02-14 in October 2002. The MT analysis has been carried out using the data at the 5 sites and another 3 sites. These additional data were collected by past experiments (Filloux, 1983; Seama et al., 2003) and the sites locate near the survey line of our experiment. Goto et al. (2003) analyzed 3 MT data sets around Marina islands and showed no thick conductive layer in the mantle wedge beneath the arc and fore arc region. In this study, we analyzed the 5 MT data sets in Mariana trough and Parece-Vela basin, so far. The MT responses were first corrected for the topographic effect which is significant especially for marine MT data. Then, the corrected responses are separated to TE and TM modes and then inverted in two-dimensional (2-D) model space independently. The responses for the

each mode is sensitive to electric current flowing either parallel or perpendicular to the 2-D strike. Obtained 2-D models for both modes have common feature that the mantle resistivity decrease from several hundreds or more to several tens or less ohm-m at the depth of 60-70 km. The mantle below 60-70 km is, however, more conductive for the model of the TM inversion than that of the TE inversion. This may indicate anisotropy that is more conductive in the direction along the profile. These features are seen in the mantle beneath southern East Pacific Rise and interpreted that the upper resistive mantle is result from drying out of olivine due to partial melting and lower conductive and anisotropic feature is manifestation of the alignment of olivine crystals to the mantle flow direction in wet condition (Baba et al., 2003). The same interpretations may be possible for the Mariana back arc basin. In addition, further analysis is now on going, which we invert all the data to obtain the model for the whole 2-D transection. The result will be presented in the meeting.

T31H-02 1035h

The Causes of Melt Differentiation at the Izu Arc Volcanic Front

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While it is common consensus that mafic arc magmas (basalts to magnesian andesites) are partial melts of the upper mantle, the provenance of the evolved arc magmas (dacites and rhyolites) remains much contested. Classic models suggest either fractional crystallization or partial melting of the upper plate crust, or a combination of both, as causes of melt differentiation. Unfortunately, it is difficult to test such models in natural systems since most arc volcanic rocks are fully crystallized, and liquid compositions cannot be directly compared to their cogenetic phenocrysts. Such possibilities, however, arise from the Cenozoic fallout tephra from the intraoceanic Izu Bonin arc. The tephra melts originate from similar mantle sources as the low-K Quaternary Izu arc front (Izu VF) volcanic rocks. Individual fallout layers from single eruptions are commonly zoned and frequently contain a range of basalt to rhyolite glass shards together with plagioclase (An₄₂₋₉₆), clinopyroxene (En₃₄₋₇₅), orthopyroxene (En₄₁₋₇₃) and titanomagnetite (Usp₁₄₋₅₀). Trace amounts of Cl-apatite (Cl=0.8-2.4 wt%) are confined to high-silica tephra, whereas olivine is absent despite its presence in the Izu VF basalt lavas. The Cenozoic tephra glasses (approximately 1500 individual glasses from 43 layers) display coherent elemental systematics through time. At any given age, the tephra glasses display a distinct bimodal distribution, with maxima at 53-54 wt% SiO₂ (basaltic andesitic) and 70-72 wt% SiO₂ (rhyolitic), respectively. Basaltic andesitic glasses overlap widely with the Izu VF lavas, whereas the dacitic-rhyolitic pole is almost exclusively represented by the tephra. Chemical and petrographic evidence of melt mixing is ubiquitous in all tephra, indicating melt mixing as important generic process. The incompatible element K varies by a factor of two in abundance at any given SiO₂. The linear mixing trends of K₂O vs. SiO₂ in individual fallout tephra, however, always have similar slopes with K₂O being always more enriched in the more siliceous glasses. It is this uniformity of the K₂O zoning, that effectively rules out that the zoned tephra melts formed by mixing of mafic and siliceous component melts that originate from either mantle and upper crustal sources (i.e. mixing of mantle melts with crustal partial melts), or by mixing of derivative melts that stem from different batches of mantle melts. Therefore, the only viable process of upper crustal differentiation appears to be mixing of cogenetic basaltic-andesite and dacitic-rhyolitic component melts that evolved by fractional crystallization from a single batch of mantle melt, and that became mixed during eruption. However, quantitative models cannot reproduce the intra-layer tephra zonation by fractional crystallization processes. Therefore, I suggest that the subducting slab may possibly play a role in the generation of the siliceous Izu VF melts. A scenario in which mafic mantle melts mix incompletely with hydrous, K₂O-bearing siliceous fluids from the slab appears to be able to explain many of the chemical and petrographic features observed in both the IzuVF tephra and lavas.

T31H-03 1050h

Coexistence of Highly-Depleted Wet Basalts and Depleted Dry Basalts in Sumisu Caldera, Izu-Bonin Arc, Japan

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