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The subduction factory: How it operates in the evolving Earth

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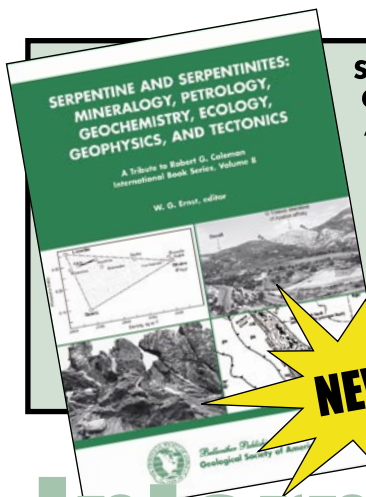
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Serpentine and Serpentinites: Mineralogy, Petrology, Geochemistry, Ecology, Geophysics, and Tectonics: A Tribute to Robert G. Coleman edited by W.G. Ernst, 2005

A symposium dealing with the plate-tectonic origin, geochemical evolution, and environmental impact of serpentinites was held 6–7 December 2003 at Stanford University, in honor of Professor Emeritus Robert G. Coleman. The technical sessions to some extent reflected his broadly diversified research thrusts. The up-to-date scientific contributions that resulted from the symposium were published in issues of *International Geology Review* and are collected in this *International Book Series* volume. The volume represents a unique collection of research subjects spanning an unusually broad spectrum of disciplines that overlap chiefly in their focus on hydrated mantle material. The book is divided into topical areas, mirroring some of Coleman's scientific contributions in mineralogy; petrology, regional geology, and plate tectonics; geochemistry; geophysics; and environmental geobotany. In aggregate, it constitutes a scholarly attempt of the scientific community to recognize some of Coleman's lifetime of extraordinary scientific achievements—especially those concerning a fuller understanding of serpentine and serpentinites.

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The George A. Thompson Volume: The Lithosphere of Western North America and Its Geophysical Characterization

edited by Simon L. Klemperer and W.G. Ernst, 2003

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Frontiers in Geochemistry: Konrad Krauskopf Volume 1 (Global Inorganic Geochemistry) and Volume 2 (Organic, Solution, and Ore Deposit Geochemistry)

edited by W.G. Ernst, 2002

The technical papers resulting from a symposium entitled "Frontiers in Geochemistry," held at Stanford University in honor of Professor Konrad B. Krauskopf, were published in separate installments in *International Geology Review* and are collected here in an attempt to recognize Krauskopf's lifetime of extraordinary achievement in both geology and geochemistry. Krauskopf has published a diverse set of international-quality investigations broadly arching across the fields of hard-rock geology, petrology, geochemistry, and mineral deposits. Detailed studies include illuminating the parageneses of granitoids and basement terranes in the Pacific Northwest, the volcanic eruptions of Parícutin in the Transmexican volcanic belt, and the regional petrologic evolution of coastal Norway. He has generated both mineral

deposit and general geologic maps for the California Division of Mines and the U.S. Geological Survey, chiefly in the Sierra Nevada and the White-Inyo ranges of eastern California. He pioneered books applying the principles of physics and chemistry to Earth and provided geoscientists with discipline-defining texts in geochemistry and physical geology over five decades. Special emphases have included elucidation of aqueous solution–metal complex equilibria as well as thermodynamic applications to solid–melt–fluid partitioning. Few geochemists have contributed to the earth sciences in such far-ranging ways as geologist, geochemist, and science and technology advisor to the nation. This two-volume set is an insufficient tribute to the legendary scientific accomplishments of Krauskopf, but it's a start!

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Ultra-High Pressure Metamorphism and Geodynamics in Collision-Type Orogenic Belts

co-edited by W.G. Ernst, and J.G. Liou, 2000

Collisional belts that retain the effects of Phanerozoic ultra-high pressure (UHP) metamorphism are increasingly being recognized, especially in Eurasia. Neighboring regions generally lack evidence of coeval arc volcanism or plutonism. Following the consumption of intervening oceanic lithosphere, each UHP orogen marks the site of astonishingly deep subduction of a microcontinental promontory or island-arc fragments. Mafic and ultramafic rocks are volumetrically minor in such belts. Maximum recorded pressures in UHP complexes approach or even exceed 2.8 GPa at temperatures of 600–900 °C. Subduction zones involve low-T prograde trajectories, and constitute the only plate-tectonic environment where such conditions exist. Internal portions of descending lithospheric plates may be characterized by yet lower geothermal gradients, but the crustal upper margins are typified by less extreme high-P, low-T paths of 5–10 °C/km. Mineral parageneses, physical conditions of recrystallization, and the tectonics of subduction and exhumation are thoroughly documented in this volume. Extensional collapse and erosion of rising sialic masses evidently aid in the continued ascent of deeply subducted but buoyant material. Surviving UHP terranes consist of relatively thin slabs of continental crust. Slices evidently rose to mid-crustal levels rapidly at remarkably high exhumation rates—approaching or exceeding 10 mm/yr. Back reaction attending decompression in all cases was

nearly complete; where UHP relics have persisted, retrogression evidently was limited by declining temperatures, coarse grain size of host minerals, and relative impermeability of the rocks to catalytic aqueous fluids. Clearly, UHP terranes provide important new constraints on the origin and tectonic evolution of collisional mountain belts.

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Tectonic Studies of Asia and the Pacific Rim: A Tribute to Benjamin M. Page (1911–1997)

co-edited by W.G. Ernst and R.G. Coleman, 2000

The late Benjamin M. Page, professor of geology of Stanford University, was a geologic mapper, regional geologist, and plate tectonician par excellence. His many research areas included western Nevada, the Apennines, southern Taiwan, and southwestern Japan, but Page's most notable and extensive works involve elucidation of the geology of the California coast ranges. Page devoted a lifetime to unraveling the geologic architecture and plate-tectonic evolution of this continental-margin mountain belt. Indeed, nearly half of the papers in this volume, including a posthumous contribution by Page, involve the tectonic history of the central California coast ranges. Topics of special concentration include the origin, evolution, and geologic occurrence of ophiolites, accretionary mélanges, continental-margin structural and/or geophysical transects, transform faults, and convergent-margin mountain belts. In 1993, the Geological Society of America recognized Page's numerous seminal scientific papers with the Career Award in Structural Geology and Tectonics.

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Integrated Earth and Environmental Evolution of the Southwestern U.S.

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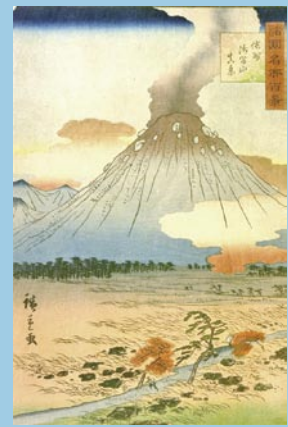
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Cover: Classic Japanese woodblock print by Hiroshige II (1829-1863) of Asama Volcano, showing an ash plume and volcanic bombs ejected by explosive activity. Image © MK Krafft CRI Nancy-Lorraine, <http://www.imagesdevolvans.fr>, dedicated to Katia and Maurice Krafft's work on volcanoes. An eruption of Asama in 1783 killed 1,491 people (U.S. Geological Survey-Smithsonian Institution map, *This Dynamic Planet*, in press). Asama, like other volcanoes on the Pacific ring of fire, is above a subduction zone. See "The subduction factory: How it operates in the evolving Earth" by Yoshiyuki Tatsumi, p. 4-10.

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CORRECTIONS to the Professional Development Program in the June issue of GSA Today are as follows.

Short Course #2. Measurement of Indoor Radon in Geologically Diverse Terrains [502]. The registration form (p. 27) shows the incorrect fee for this course of \$150. The correct fee is \$360. (The \$150 pertains to an additional fee to take the optional exam and earn a Radon Measurement Specialist Certificate.)

Short Course #6. Three-Dimensional Geologic Mapping for Groundwater Applications Workshop [506]. The correct fee for this workshop is \$195.

The subduction factory: How it operates in the evolving Earth

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ABSTRACT

The subduction factory processes raw materials such as oceanic sediments and oceanic crust and manufactures magmas and continental crust as products. Aqueous fluids, which are extracted from oceanic raw materials via dehydration reactions during subduction, dissolve particular elements and overprint such elements onto the mantle wedge to generate chemically distinct arc basaltic magmas. The production of calc-alkalic andesites typifies magmatism in subduction zones. One of the principal mechanisms of modern-day, calc-alkalic andesite production is thought to be mixing of two end-member magmas, a mantle-derived basaltic magma and an arc crust-derived felsic magma. This process may also have contributed greatly to continental crust formation, as the bulk continental crust possesses compositions similar to calc-alkalic andesites. If so, then the mafic melting residue after extraction of felsic melts should be removed and delaminated from the initial basaltic arc crust in order to form “andesitic” crust compositions. The waste materials from the factory, such as chemically modified oceanic materials and delaminated mafic lower crust materials, are transported down to the deep mantle and recycled as mantle plumes. The subduction factory has played a central role in the evolution of the solid Earth through creating continental crust and deep mantle geochemical reservoirs.

INTRODUCTION

Subduction zones, where the oceanic plates sink into the mantle, have been “factories” since plate tectonics began on Earth (Fig. 1). Oceanic materials such as pelagic and terrigenous sediments, altered and fresh basaltic oceanic crust, and mantle lithosphere enter the factory as raw materials. These materials, together with mantle-wedge peridotites, are processed into products, during which the entire factory adjusts and deforms, causing magmatism and earthquakes. The products of the factory are arc magmas, their solidified materials, and ultimately continental crust. Such products may be volumetrically small, as the continental crust occupies <1% of the total mass of solid Earth. However, they possess “differentiated” compositions, quite distinct from a chondritic bulk Earth, which suggests that the origin of products from the subduction factory should provide a clue to understanding the evolution of the solid Earth.

The subduction factory, as do other factories, emits waste materials, such as slab materials, which are chemically modified through complex dehydration and/or melting processes

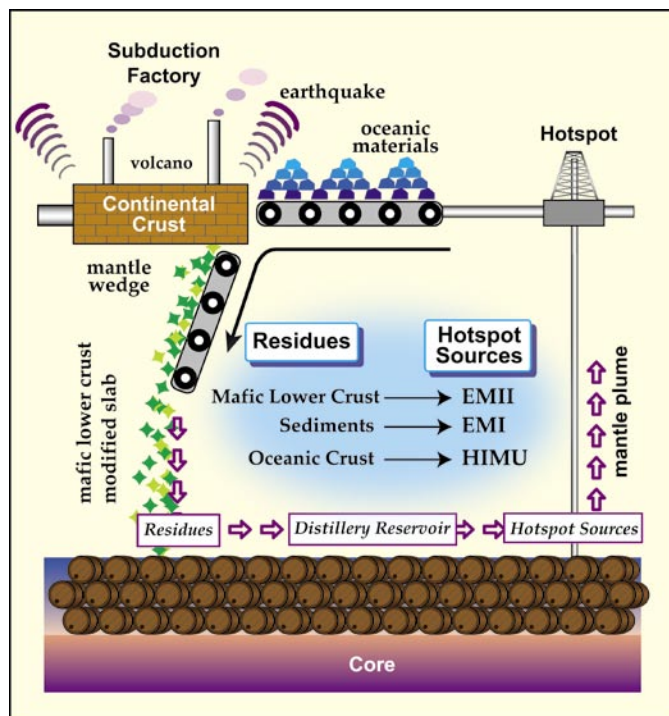


Figure 1. Role of the subduction factory in the evolution of the solid Earth. Raw materials, such as oceanic sediments, oceanic crust, mantle lithosphere, and wedge materials, are fed into the factory and are manufactured into arc magmas and continental crust. The waste materials or residues processed in this factory, such as chemically modified slab components (oceanic crust and sediments) and delaminated mafic lower arc crust, are transported and stored in the deep mantle and recycled as raw materials for mantle plume-related hotspot magmatism. EMI—enriched mantle type I; EMII—enriched mantle type II; HIMU—high- μ mantle.

during subduction, and possibly delaminated mafic lower-arc crust. These waste materials founder into Earth’s deeper interior, reside somewhere in the deep mantle, and may contribute greatly to the evolution of mantle because of their significant mass and characteristic compositions; assuming steady-state subduction of the entire 7-km-thick oceanic crust for 3 billion years, accumulated crust materials with basaltic compositions occupy ~10% of the lower mantle.

This paper outlines how the subduction factory creates products and discusses its role in the evolution of Earth’s mantle.

PRODUCTION PROCESSES

Subduction zones are sites of intensive volcanism and are creating >20% of the current terrestrial magmatic products.

Although the interaction of physical and chemical processes occurring in subduction zones is complex, arc magmatism exhibits characteristics common to not all but most arc-trench systems. One of these general characteristics is the presence of paired lines of volcanoes. Another is the negative correlation between the volcanic arc width and the subduction angle (Fig. 2A). In other words, the depth to the surface of the subducting lithosphere is constant at ~110 km and ~170 km, respectively, beneath the trenchward limit of the volcanic arc (the volcanic front) and the backarc-side volcanoes (Fig. 2B). This characteristic volcano distribution relative to subduction depth suggests an important role of pressure-dependent processes such as dehydration reactions in magma generation in the subarc mantle. As emphasized by Tatsumi and

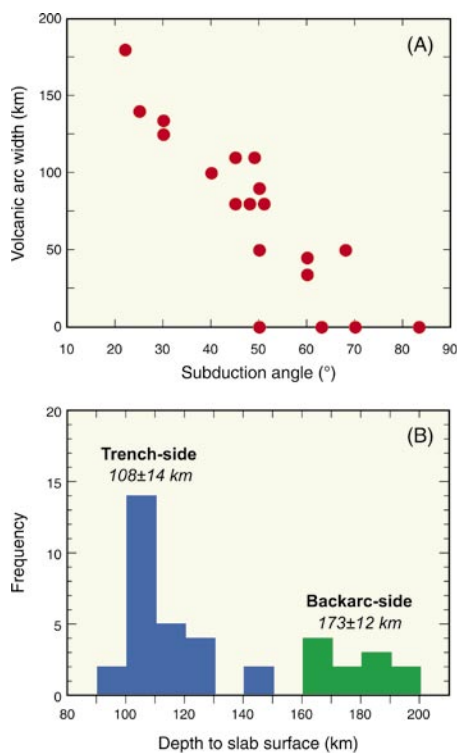


Figure 2. Tectonic characteristics of subduction zone magmatism (Tatsumi and Eggins, 1995). (A) Negative correlation between the subduction angle and the volcanic arc width. (B) Constant depths to the surface of the subducting lithosphere beneath the trench-side (volcanic front) and backarc-side volcanic chains in volcanic arcs. Noted values are the average depths and one standard deviation. These observations suggest the primary role of pressure-dependent reactions in production of arc magmas.

Eggins (1995), the characteristic depths correspond to pressures expected for the dehydration of amphibole and chlorite (110 km) and phlogopite (170 km) in the hydrous peridotite layer at the base of the mantle wedge, which is formed by addition of slab-derived aqueous fluids beneath the forearc and dragged downward on the subducting plate.

Within any volcanic arc, lava chemistry tends to change systematically with distance from the volcanic front. The degree of silica saturation decreases toward the backarc (Kuno, 1966) with increasing concentrations of incompatible elements such as K, Rb, and Zr, a relationship known as the *K-h* (K, potassium; *h*, height above the slab) relationship (Dickinson, 1975). A possible origin of this observation is separation of a primary magma from an adiabatically rising mantle diapir at a greater depth by a lower degree of partial melting toward the backarc, which may be caused by the presence of a thicker lithosphere beneath the backarc side of a volcanic arc (e.g., Tatsumi et al., 1983; Zhao et al., 1992; Furukawa, 1993).

Selective enrichment of particular incompatible elements in arc basalts has been well established since the pioneer work by Pearce and Cann (1973). This can be intuitively attributed to addition of the slab-derived component to the original mantle wedge. Herein the geochemical characteristics of arc magmas and their possible causes including element transport from the downgoing oceanic lithosphere will be further outlined.

Basaltic Magma

Although basalts are not always the major surface products of the subduction factory, magmas generated in the mantle wedge are likely to be basaltic in composition. Basalts erupted in subduction zones are noted for their distinct chemistry compared with those in other tectonic settings. In particular, they are elevated in large ion lithophile elements (e.g., Cs, Rb, K, Ba, Pb, Sr) and depleted in high field strength elements (e.g., Ta, Nb, Zr, Ti) (Fig. 3). Such characteristic compositions likely arise from subducting oceanic lithosphere through metasomatic reactions between the subducting lithosphere and the overlying mantle wedge. What is the nature of the metasomatic process that

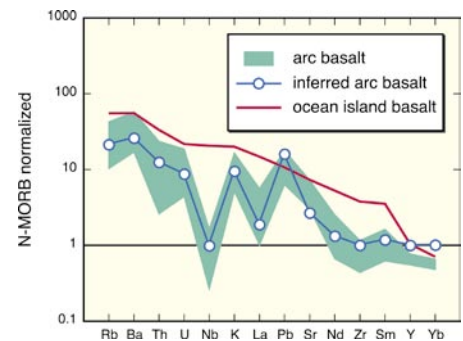


Figure 3. Normal mid-oceanic-ridge basalt (N-MORB)-normalized (Sun and McDonough, 1989) incompatible element characteristics of arc basalts (Tatsumi and Eggins, 1995), an arc basalt magma inferred from geochemical modeling on element transport by dehydration of subducting sediments and altered oceanic crust (Tatsumi and Kogiso, 2003), and a hotspot-related oceanic-island basalt (Sun and McDonough, 1989).

enriches the source region of subduction zone magmas? Since the work of Nicholls and Ringwood (1973), many petrologists have favored mechanisms including slab melting and subsequent melt-mantle interaction. A majority of researchers, however, currently believe that the subducting lithosphere dehydrates but does not melt except in arc-trench systems where a young and hot plate is being subducted (Peacock et al., 1994). During the Archean, however, temperatures of both the upper mantle and the subducting crust might have been higher, which could cause slab melting, rather than slab dehydration (Martin, 1987). This possibility will be discussed later.

Under upper mantle *P-T* conditions, H₂O exists as a supercritical fluid, which can dissolve additional components and elements to a certain extent. Therefore, aqueous fluid phases released by dehydration reactions within the subducting lithosphere may be a likely metasomatic agent responsible for the characteristic trace element signatures. To elucidate the geochemical characteristics of such slab-derived fluid phases, several experimental studies have been conducted on the distribution of elements between aqueous fluids and solid minerals (e.g., Tatsumi et al., 1986; Brenan et al., 1995; Keppler, 1996). On the basis of these experimental data, together with reasonable assumptions of H₂O contents (1.5 wt%) in both subducting oceanic

materials and arc magmas, the preflux and original subarc mantle compositions (normal mid-oceanic-ridge basalt source), Tatsumi and Kogiso (2003) demonstrated that the geochemical characteristics of arc basalts could be reasonably explained by addition of elements from subducting sediments and oceanic crust through dehydration processes (Fig. 3). On the other hand, Elliott et al. (1997) suggested that slab-derived melts are one possible medium for modifying the mantle wedge so as to make potential sources for some basaltic magmas even in the Mariana arc where subduction of the oldest oceanic lithosphere on Earth causes arc magmatism. Miscibility between silicate melts and hydrous fluids under upper mantle conditions (e.g., Bureau and Keppler, 1999) could explain the complex metasomatic agents in subduction zones as products of both melting and dehydration.

If element transport by slab-derived fluid phases could be accepted as one major process responsible for the distinctive chemistry of arc basalt magmas, then the fate of dehydrated and chemically modified residues (both sediments and basalts), especially their role in the mantle evolution, should be equally interesting.

Andesitic Magma

Andesite erupts in >80% of arc volcanoes, typifies magmatism in subduction zones, and is the most dominant volcanic rock in mature continental arcs. In addition to this volumetric importance, the continental crust, the geochemical reservoir for light elements and the most differentiated end-member among components within the solid Earth, is of overall andesitic composition (e.g., Taylor, 1995; Rudnick, 1995). Knowledge of andesite genesis should therefore provide key constraints on the origin of continental crust and differentiation processes during early Earth evolution.

Although andesite is defined simply as sub-alkalic, intermediate volcanic rock, its origin is not unique. Two distinctive differentiation trends, tholeiitic (TH) and calc-alkalic (CA), are recognized in the andesitic volcanic rocks of arcs, denoting the presence or absence of relative iron-enrichment

during magmatic differentiation (Wager and Deer, 1939). FeO^*/MgO versus SiO_2 variation plots (FeO^* , total iron as FeO) (Miyashiro, 1974) are commonly used to distinguish the two magma series (Fig. 4A); CA and TH trends generally have steeper and gentler slopes, respectively, than the straight line in Figure 4A. Although the definition of CA versus TH should be based exclusively on differences in degree of relative iron enrichment, inconsistent usage of these magma series has in the past caused confusion. One such example is the interchangeable use of the terms medium-K and CA series (e.g., Hess 1989). Another problem is the applica-

tion of Miyashiro's discrimination line as a simple compositional discriminant rather than applying a more desirable "trend slope" comparison (e.g., Hunter and Blake, 1995).

One of the most distinct chemical differences between CA and TH series rocks, other than the difference in degree of iron-enrichment, is the characteristic differentiation trend of MgO versus SiO_2 (Fig. 4B); while TH rocks tend to show a concave trend, CA rocks exhibit a straighter trend. It is generally accepted that the TH differentiation trend can be largely reproduced by fractionation of phenocryst phases such as olivine, plagioclase, and pyroxene from a parental basaltic magma (e.g., Sakuyama, 1981; Grove and Baker, 1984; Fujinawa 1988), which is also supported by MELTS modeling (Ghiorso and Sack, 1995) for a basaltic magma in the presence of 0.5 wt% H_2O at 0.2 GPa under a quartz-fayalite-magnetite (QFM) buffer (Fig. 4).

On the other hand, the genesis of CA andesites poses a considerable question for debate. One possible cause for the characteristic CA trend is the effective separation of Fe-Ti oxide that can prevent iron enrichment (e.g., Osborn, 1959; Gill, 1981). Grove and coworkers (e.g., Sisson and Grove, 1993; Grove et al., 2003) provided a comprehensive experimental data set of liquid lines of descent for basaltic and andesitic magmas under hydrous conditions, demonstrating that a high magmatic H_2O content reduces the stability of silicate minerals. This has less effect on Fe-Ti oxide stability, resulting in early magnetite crystallization in hydrous magmas. It is thus likely that hydrous basalt, and even mantle-derived andesitic magmas, can fractionate to form a CA trend (Fig. 4). If this is the case, then the primary factor controlling the production of the two arc magma series is the H_2O content in the magma source region (i.e., more hydrous for CA magma generation). However, this elegant explanation may not account for the observation that CA andesites commonly exhibit the following disequilibrium petrographic characteristics, which suggest a role for magma mixing in their formation (Eichelberger, 1975; Sakuyama, 1981; Bloomfield and Arculus, 1989; Clynne,

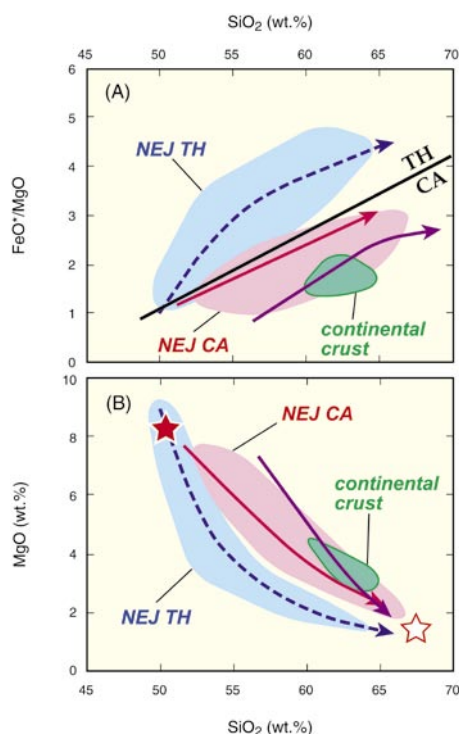


Figure 4. Major element characteristics for calc-alkalic (CA) and tholeiitic (TH) rocks from NE Japan (NEJ) arc and the bulk continental crust (data from Tatsumi and Kogiso, 2003). (A) CA and TH trends generally have steeper and gentler slopes, respectively, than the straight line in a SiO_2 versus FeO^*/MgO diagram (Miyashiro, 1974). (B) While TH rocks tend to show a concave trend in a SiO_2 versus MgO diagram, CA rocks exhibit a rather straight trend. Solid and broken lines with arrows indicate the liquid lines of descent obtained by experiments at 0.2 GPa by Grove and coworkers (e.g., Sisson and Grove, 1993; Grove et al., 2003) and MELTS calculation (see text). Mixing of basaltic and felsic magmas (filled and open stars in Fig. 4B) can explain a rather linear trend for CA series rocks.

1999): (1) the presence of plagioclase phenocrysts with a dusty zone containing fine melt inclusions and with a wide range of compositions; (2) the presence of reversely zoned pyroxene phenocrysts with rounded cores mantled by rims with higher Mg/Fe ratios; (3) the presence of subhedral to rounded olivine phenocrysts rimmed by pyroxene; and (4) the occurrence of disequilibrium mineral assemblages such as Mg-rich olivine and quartz. Mixing of mafic and felsic end-member magmas can form linear trends on variation diagrams (Fig. 4).

If we accept magma mixing as one possible mechanism responsible for the petrographic and chemical characteristics of CA andesites, then an ensuing question involves the origin of end-member components in magmas, one basaltic and formed at higher T , the other more differentiated and formed at lower T . A key observation in this problem is a systematic difference in isotopic composition between CA and TH series rocks, as documented at least in some Quaternary volcanoes in the NE Japan arc (Fujinawa, 1988; Tatsumi and Kogiso, 2003). If this observation may be generalized to other arcs, then the two end-member magmas could be derived from different sources. Therefore, “self mixing” (Couch et al., 2001) or “internal mixing,” in which felsic and mafic magmas are essentially co-magmatic, does not likely play a major role in CA andesite formation. Alternatively, a felsic end-member magma could form by anatexis of preexisting arc crust and mix with a mantle-derived basaltic magma, which may be considered “external mixing.” Furthermore, the origin of the basaltic end-member magma is still a matter of debate. Is it a TH basalt? Or, does a mantle-derived CA basalt exist? To improve our understanding of andesite genesis, detailed descriptions of the two magma series rocks from a single volcano are needed.

Continental Crust Formation

The continental crust has an average composition equivalent to CA andesites (Fig. 4) that typify arc magmatism and hence is believed to be created at convergent plate margins (e.g., Kelemen, 1995; Taylor, 1995; Rudnick, 1995). However, modern-day, mantle-derived

magmatism in such settings is dominated by basalt. This dilemma faces anyone interested in the theory of continental crust formation. Herein, possible alternative solutions are considered: (a) direct production of andesitic magmas, and (b) mechanical fractionation of basaltic arc crust to remove the mafic part.

The majority of continental crust was created in the Archean, when the geotherm was steeper and hotter, and it is possible that Archean slab melting, instead of slab dehydration as at present, could have been responsible for production of dominantly andesitic as opposed to basaltic magmas (Shirey and Hanson, 1984; Martin, 1987; Drummond and Defant, 1990; Kelemen, 1995; Rapp et al., 1999). High- P experiments (Rapp et al., 1999) demonstrated that slab melting and subsequent interaction of Si-rich slab-melt with Mg-rich mantle can reproduce andesitic compositions similar to the continental crust. Modeling based on geochemical formulation of partial melting and melt-solid reactions (Tatsumi, 2000a)

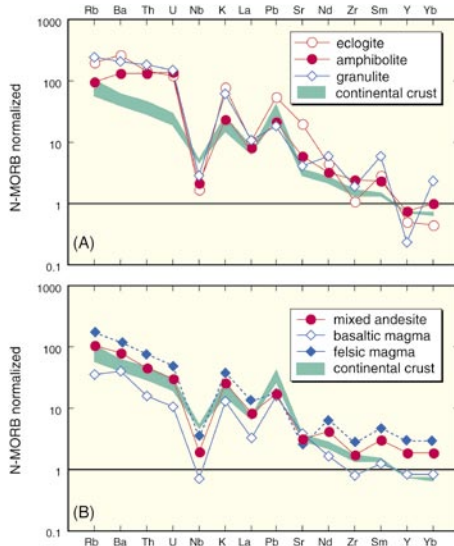


Figure 5. Normal mid-oceanic-ridge basalt (N-MORB)-normalized (Sun and McDonough, 1989) incompatible element characteristics of the bulk continental crust (Taylor, 1995; Rudnick, 1995) and modeled inferred andesite magmas. (A) Andesitic magmas are assumed to be produced by slab melting under three representative P - T conditions (eclogite, amphibolite, and granulite facies) and subsequent melt-mantle interactions (Tatsumi, 2000a). (B) An andesitic magma is produced by mixing between a basaltic magma produced by slab dehydration induced by mantle melting and a felsic magma formed by remelting of the initial basaltic arc crust (Tatsumi and Kogiso, 2003).

has confirmed that this mechanism can also account for trace element characteristics of bulk andesitic continental crust (Fig. 5A).

Alternatively, an andesitic magma having compositions similar to the bulk continental crust can be also produced by mixing of a basaltic magma generated by mantle melting induced by slab dehydration with a felsic magma produced by partial melting of the initial basaltic arc crust, as geochemically modeled by Tatsumi and Kogiso (2003) (Fig. 5B). This process of andesitic crust formation is identical to that envisioned for CA andesite production operating in current subduction zones. Although this mixing process can create the andesitic crust, the composition of the total crust is still basaltic, not andesitic. In order to make an andesitic continental crust, therefore, the mafic lower crust, which is a melting residue after segregation of felsic magma, should be extracted from the arc crust. One possible extraction mechanism would be delamination of the lower part of initial basaltic arc crust, because the melting residue may be composed of mafic rocks, containing dense minerals such as garnet and Fe-Ti oxides, that ultimately sink into the mantle (Turcotte, 1989; Kay and Kay, 1993; Nakajima and Arima, 1998; Jull and Kelemen, 2001).

In summary, the major and incompatible trace element characteristics of andesitic bulk continental crust can be explained by either slab melting or by magma mixing in association with delamination of mafic lower crust. However, waste materials after processing are different for the two mechanisms: melting residue of basaltic oceanic crust at mantle pressures and that of basaltic arc crust at crust pressures for the slab melting and delamination, respectively. This difference will be further examined isotopically in the following section.

RECYCLING PROCESSES

Surface materials such as crust and sediments, from which certain components are extracted during subduction, are injected into the mantle, resulting in significant chemical heterogeneity in the deep mantle. Although the physical properties of descending surficial and mantle materials have been investigated

at high pressures (e.g., Ringwood, 1991; Ono et al., 2001; Guignot and Andrault, 2004), the location in the mantle where subduction components are stored is still beyond consensus.

It has been suggested from geochemical studies on mid-oceanic-ridge basalts (MORBs) and oceanic-island basalts (OIBs) that at least four end-member components or geochemical reservoirs in addition to primitive mantle are needed to explain the isotopic diversity of oceanic basalts (e.g., Zindler and Hart, 1986; Hofmann, 1997): depleted MORB mantle (DMM), enriched mantle types I and II (EMI and EMII), and high- μ mantle (HIMU). It is generally believed that DMM, with its distinct isotopically depleted signature, occupies the shallowest upper mantle, whereas other enriched mantle components typify magmas rising from deep-seated hotspots. It may therefore be illuminating to discuss linkages among three enriched geochemical end-members in the deep mantle and waste materials generated in the subduction factory such as sediment, oceanic crust, and possibly delaminated mafic lower crust.

Dehydrated Oceanic Crust and HIMU

The HIMU, or high- μ ($\mu = {}^{238}\text{U}/{}^{204}\text{Pb}$), source is characterized by higher ${}^{206}\text{Pb}/{}^{204}\text{Pb}$ and ${}^{187}\text{Os}/{}^{186}\text{Os}$, but depleted MORB-like ${}^{87}\text{Sr}/{}^{86}\text{Sr}$ and ${}^{143}\text{Nd}/{}^{144}\text{Nd}$ compared to other end-member components (Zindler and Hart, 1986; Hauri and Hart, 1993). These isotopic signatures, particularly high ${}^{206}\text{Pb}/{}^{204}\text{Pb}$, have been generally considered to be related to depletion of Pb relative to U by dehydration processes in subduction zones (e.g., Chauvel et al., 1992; Brenan et al., 1995; Kogiso et al., 1997). Because Nd is extracted from subducting altered oceanic crust more readily than Sm (Keppler, 1996; Kogiso et al., 1997), ancient residual dehydrated oceanic crust has higher ${}^{143}\text{Nd}/{}^{144}\text{Nd}$ than the HIMU component (Fig. 6A), suggesting that HIMU cannot be created solely by the contribution of dehydrated subducting crust. Instead, Tatsumi and Kogiso (2003) demonstrated that isotopic signatures of HIMU could be reasonably explained by accumulation of

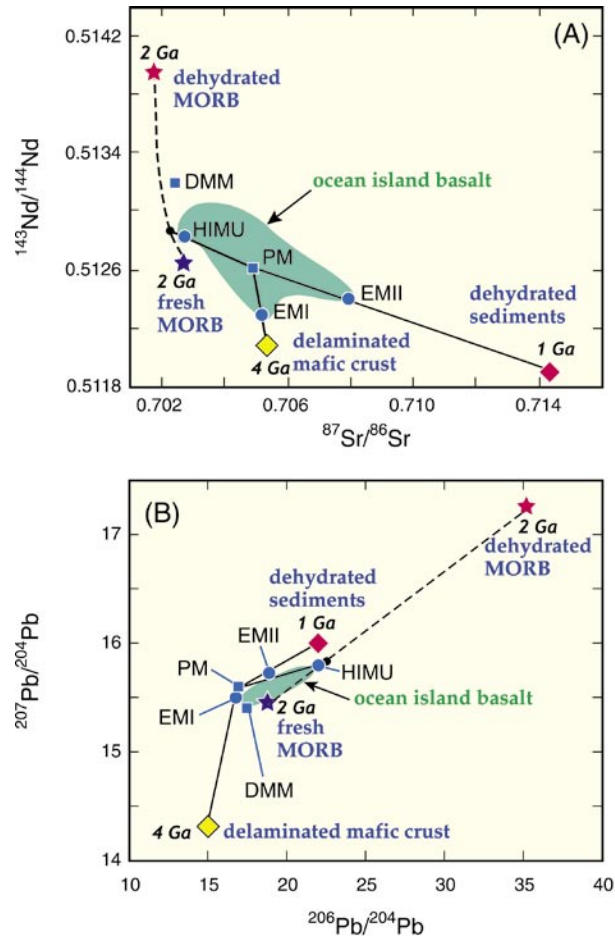


Figure 6. Isotopic compositions of inferred waste materials from the subduction factory (dehydrated/fresh oceanic crust, Tatsumi and Kogiso, 2003; dehydrated sediment, Aizawa et al., 1999; delaminated mafic lower crust, Tatsumi and Kogiso, 2003) and mantle geochemical reservoirs (DMM—depleted mid-oceanic-ridge basalt mantle; HIMU—high- μ mantle; EMI—enriched mantle type I; EMII—enriched mantle type II; MORB—mid-oceanic-ridge basalt; PM—primitive mantle) that have been proposed to explain the isotopic diversity observed for ocean island basalts. Evolution of deep mantle reservoirs may be comprehensively explained by contribution of recycled waste materials from the subduction factory and primitive mantle.

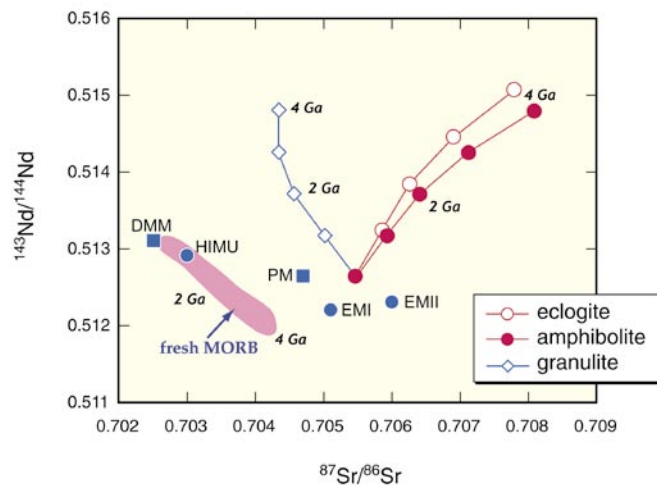


Figure 7. The isotopic evolution of the slab restites produced after extraction of slab melts at three representative P - T conditions (eclogite, amphibolite, and granulite facies; Tatsumi 2000b) and fresh mid-oceanic-ridge basalt (MORB) (Tatsumi and Kogiso, 2003), with ages of formation. Isotopic compositions of mantle geochemical reservoirs (DMM—depleted MORB mantle; HIMU—high- μ mantle; EMI—enriched mantle type I; EMII—enriched mantle type II; and PM—primitive mantle) are also shown. Mixing of slab restites with fresh MORB and/or PM cannot explain the geochemical characteristics of enriched geochemical reservoirs such as EMI, EMII, and HIMU.

both 2 Ga fresh and dehydrated MORB crust in the deep mantle (Fig. 6).

Dehydrated Sediment and EMII

The role of subducting sediments in the evolution of EMII is commonly advocated, because oceanic sediments generally have high $^{87}\text{Sr}/^{86}\text{Sr}$ and relatively low $^{143}\text{Nd}/^{144}\text{Nd}$ (e.g., Devey et al., 1990). Experimental results on sediment dehydration and associated element transport (Aizawa et al., 1999; Johnson and Plank, 1999) have demonstrated that chemically modified, dehydrated ancient subducted oceanic sediments, a waste material from the subduction factory, may evolve to an enriched component having high $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{206}\text{Pb}/^{204}\text{Pb}$. Aizawa et al. (1999) further suggest that the isotopic signature of the EMII component can be achieved by the addition of small amounts (~1 wt%) of 1 Ga dehydrated sediments to primitive mantle (Fig. 6).

Melting Residue of Sinking Oceanic Crust

Partial melting of the sinking basaltic oceanic crust may have taken place more widely during Earth's early history and could have contributed to continental crust formation. If this is the case, then the restites of slab melting, with compositions distinct from the bulk mantle, may have formed a geochemical reservoir in the deep mantle and could have been recycled as a hotspot source. Figure 7 shows the Sr-Nd isotopic evolution of the predicted slab restites formed under three representative *P-T* conditions (Tatsumi, 2000a). The isotopic characteristics of these slab residues and their mixtures with fresh MORB crusts do not match those of any proposed geochemical end-member mantle component. This may lead to the conclusion that the slab melting did not play the major role in the continental crust formation during the Archean, although it could account for the geochemical characteristics of the bulk continental crust.

Delaminated Mafic Lower Crust and EMI

We now examine linkages between delaminated arc crust and EMI. To make andesitic continental crust, melting residue following extraction of felsic melts needs to be removed and delaminated

from initial basaltic arc crust. This mafic lower crust material could contribute to evolution of a deep-seated geochemical reservoir. Important for evaluating the isotopic evolution of melt residues in the initial basaltic crust is the degree of separation of felsic melts from partially molten crust, as the viscosity of felsic melts may be about two orders of magnitude higher than that of basaltic melts under similar hydrous conditions. Geochemical modeling incorporating the effects of remaining felsic melts (Tatsumi and Kogiso, 2003) indicates that the Sr-Nd-Pb isotopic characteristics of EMI can be best explained by contribution of 3–4 Ga delaminated crustal material mixed with a 10%–15% felsic melt component (Fig. 6).

CONCLUSIONS

Raw materials entering the subduction factory are processed into magmas, which erupt as characteristic arc volcanism and construct continental crust. The waste materials from the factory, such as chemically modified subducting sediment and crust, and melt residue delaminated from initial arc crust, have accumulated in the deep mantle and probably evolved into enriched geochemical reservoirs such as EMII, HIMU, and EMI, respectively. Magmas that tap these deep-seated geochemical end-member components erupt where mantle plumes rise from the deep mantle. It is thus possible to conclude figuratively that the subduction zone has been working nearly as a zero-emission factory in which the solid waste materials (i.e., excluding magmatic gases) are largely recycled and reused as raw materials within the hotspot factory. Recycling of surface crustal materials through subduction factories and mantle plumes may have played the central role in the evolution of the solid Earth.

ACKNOWLEDGMENTS

Stimulating discussions about arc magma genesis with members of the Institute for Research on Earth Evolution (IFREE) are acknowledged, although not all of them will agree with the ideas and conclusions presented herein. Thanks also to Mike Coffin, Simon Johnson, Jon Blundy, James Gill, William Leeman, Stephen Parman, Tom Sisson, and editor Keith Howard

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CORRECTION

In the March 2005 *GSA Today* article by Fastovsky and Sheehan, “The extinction of the dinosaurs in North America,” the second paragraph under the heading “Causes: So What Killed the Dinosaurs?” (p. 7) should read:

Our interest, however, is in published models that are grounded in data and that are potentially testable. In this category, Archibald and Bryant (1990), basing their interpretations upon patterns of vertebrate survivorship,

proposed marine regression with associated habitat fragmentation as the ultimate cause of the K-T extinctions. In this model, multiplication and lengthening of river systems due to a marine regression led to a diminution and fragmentation of coastal plain habitats, in turn causing range reductions and eventual extinction. A variation on this model was proposed by Archibald (1996, 1997) and Dingus and Rowe (1997), who suggested that the regression in combination with latest Cretaceous igneous activity and the asteroid impact caused the extinction of the dinosaurs.

Comment and Reply
The extinction of the dinosaurs in North America, David E. Fastovsky and Peter M. Sheehan, *GSA Today*, v. 15, no. 3, p. 4–10.

Comment

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“The extinction of the dinosaurs in North America,” by Fastovsky and Sheehan in the March 2005 issue of *GSA Today* addressed two controversial topics: the rate of decline in dinosaur diversity approaching the Cretaceous-Tertiary (K-T) boundary and the “instantaneous extinction” of the dinosaurs at the K-T boundary in North America.

Addressing the “instantaneous extinction” topic, Fassett and others (2002) provided two independent lines of evidence supporting the presence of Paleocene dinosaurs in the San Juan Basin of New Mexico: (1) Paleocene index palynomorphs that are present stratigraphically below dinosaur bone at two localities, 35 mi apart, in the San Juan Basin; and (2) dinosaur bone that is found in abundance in the southern part of the basin in magnetochron c29N in the Paleocene Ojo Alamo Sandstone. These data not only indicate that dinosaurs survived beyond the end of the Cretaceous in the San Juan Basin, but because of the precise dating of c29N on geologic time scales, we know that the surviving dinosaurs lived on into the Paleocene for about 1.0 m.y. It is thus puzzling why Fastovsky and Sheehan have ignored the Fassett et al. (2002) publication that directly refutes their claim that dinosaur extinction in North America was “geologically instantaneous” at the K-T boundary.

Even though biostratigraphic data in Wyoming and Montana may indicate the sudden extinction of dinosaurs at the K-T boundary, compelling biostratigraphic data from New Mexico show that these fascinating creatures lived on into the Paleocene for another 1.0 m.y. and thus did not become “instantaneously extinct” at the end of the Cretaceous.

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doi: 10.1130/1052-5173(2005)015<11:TEOTDC>2.0.CO;2

Reply

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Our conclusion (Fastovsky and Sheehan, 2005), that non-avian dinosaurs underwent a geologically instantaneous extinction, is unaffected whether Fassett is wrong (the “Paleocene” dinosaurs are actually Cretaceous) or right (a few dinosaurs survived into the Paleocene).

Fassett is wrong: Fassett cites two instances of pollen-dated dinosaur material, as well as magnetostratigraphic evidence. The first instance, an isolated femur, is likely reworked. In the second, re-analysis of pollen from the same locality indicates a Maastrichtian age (Sullivan et al., 2003). This is concordant with the recovery, in the same deposits, of Maastrichtian mammalian index taxa (Weil and Williamson, 2000).

With the biostratigraphy unresolved, the assignment of normal and reversed magnetic polarity zones in the SJB to global magnetochrons remains tenuous. The issue is further complicated by the likelihood of post-Paleocene remagnetization (Butler, 1985). We thus cannot rule out the possibility that the stratigraphy proposed by Fassett is flawed.

Fassett is right: Consider an analogy by paleontologist Peter Dodson (1993, personal commun.): we might see a Model T on the road, but we would never conclude that the car was part of a modern automotive (metaphorical) ecosystem. Even if a few dinosaurs survived a million years past the K-T boundary, dinosaurs were casualties of an extinction that, the best evidence suggests, was geologically instantaneous.

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**THE GEOLOGICAL SOCIETY
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GSA Names 2005 Medal and Award Recipients

GSA medals and awards for 2005 will be presented during the Presidential Address and Awards Ceremony at the Annual Meeting in Salt Lake City on Saturday, 15 October, at the Hilton Salt Lake City Center Grand Ballroom.

Penrose Medal

Minze Stuiver
University of Washington

Arthur L. Day Medal

Donald W. Forsyth
Brown University

Young Scientist (Donath) Medal

Demian M. Saffer
Pennsylvania State University

GSA Distinguished Service Award

Ben A. van der Pluijm
University of Michigan, Ann Arbor

GSA Public Service Award

J. David R. Applegate
U.S. Geological Survey, Reston, Va.

Honorary Fellows

Alfred Kröner
Universität-Mainz, Germany

Sir Nicholas J. Shackleton
The Godwin Lab, Cambridge, UK

John J. Veevers
Macquarie University, Australia

Subaru Outstanding Woman in Science Award (Sponsored by Subaru America, Inc.)

Michelle A. Walvoord
U.S. Geological Survey, Denver, Colo.

AGI Medal in Memory of Ian Campbell

Name not available at this time

John C. Frye

Environmental Geology Award
Name not available at this time

Rip Rapp Archaeological Geology Award

C. Reid Ferring
University of North Texas

Gilbert Cady Award (Coal Geology Division)

Arthur D. Cohen
University of South Carolina

E.B. Burwell, Jr., Award (Engineering Geology)

Name not available at this time

George P. Woollard Award (Geophysics Division)

Anthony Watts
University of Oxford, UK

Mary C. Rabbitt Award (History of Geology Division)

Gerald M. Friedman
Brooklyn College and Northeastern Science Foundation

O.E. Meinzer Award (Hydrogeology Division)

Donald I. Siegel
Syracuse University

G.K. Gilbert Award (Planetary Geology Division)

Lionel Wilson
Lancaster University, UK

Kirk Bryan Award (Quaternary Geology and Geomorphology Division)

John C. Gosse
Dalhousie University

Fred M. Phillips
New Mexico Institute of Mining and Technology

Lawrence L. Sloss Award (Sedimentary Geology)

Teresa Jordan
Cornell University

Career Contribution Award (Structural Geology and Tectonics Division)

Jan Tullis
Brown University

Distinguished Career Award (International Division)

None awarded for 2005.

GSA Presidential Address & Awards Ceremony

Sat., 15 Oct., 7–9 p.m.

Hilton Salt Lake

City Center

Grand Ballroom

Join us Saturday to honor your fellow geoscientists—the award recipients, newly elected GSA Fellows, and Honorary Fellows—at the Presidential Address and Awards Ceremony, which will be followed by a reception.

We hope to see you there!

GSA Fellows Elected by Council on 15 May 2005



THE GEOLOGICAL SOCIETY
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Suzanne L. Baldwin

Associate Professor, Syracuse University

Suzanne Baldwin is nominated in recognition of her outstanding contributions in application of $^{40}\text{Ar}/^{39}\text{Ar}$, U-Pb microprobe, and U-Th/He methods to problems in the development of core complexes, rift propagation, and the pressure-temperature-time evolution of crustal terranes. Moreover, she is recognized as a superb teacher of both undergraduate and graduate students.

Terence D. Barr

Executive Vice President, AFEX International, Inc.

Terence Barr's most successful academic career began in Australia. He distinguished himself and his research team, publishing truly seminal papers in geodynamics. He also proved a popular teacher. His career change to the petroleum industry, as executive vice president of AFEX International, further demonstrates his tremendous intellectual and technical capabilities.

Barbara A. Bekins

Research Hydrologist, U.S. Geological Survey

Barbara Bekins is elected for insightful, quantitative contributions to (1) the hydrogeology of active tectonic environments in which pore pressure impacts fault strength, and (2) the active geochemical role of microbial populations in mitigating groundwater contamination by hydrocarbons. She also

achieved exceptional outreach to a diverse geological community as the Birdsall-Dreiss Distinguished Lecturer.

John W. Bell

University of Nevada-Reno
Elected to Fellowship as the 2004 Burwell awardee.

Joel D. Blum

Professor, University of Michigan

Joel Blum has cleverly applied the tools of isotope geochemistry to difficult questions of environmental chemistry and thereby contributed greatly to our understanding of the role of weathering in the global carbon cycle and to our understanding of the marine strontium record.

Stephen G. Brush

University of Maryland
Elected to Fellowship as the 2004 History of Geology awardee.

Peter A. Cawood

Professor, University of Western Australia

Peter Cawood, director of the Tectonics Special Research Centre, University of Western Australia, is noted for his contribution on the tectonic and paleographic setting of orogenic systems from around the world, most notably those along the Pacific margin of Gondwana and the Appalachian/Caledonian chain.

Ibrahim Cemen

Professor, Oklahoma State University

Ibrahim Cemen, Chair of the School of Geology at

Oklahoma State University, is nominated for the following contributions to the profession of geology: numerous excellent publications, training of future geologists, administration of geological programs, and his applied research. He has made many valuable contributions, especially in the Arkoma Mountains and Ouachita Mountains.

Francis H. Chapelle

U.S. Geological Survey

Elected to Fellowship as the 2000 Meinzer awardee.

Ward Chesworth

Professor Emeritus, University of Guelph

Ward Chesworth's contributions are based on research as a geochemical petrologist focusing on soil petrology, defining conditions for sustainable agriculture through reducing stresses, demands, and abuses on Earth, including water, soil, and the environment. He has made major basic contributions to the application of geology for sustainable societies.

Sun-Lin Chung

Professor, National Taiwan University

Sun-Lin Chung has made significant contributions to Tibetan tectonomagmatic evolution, the genesis of Emeishan LIP, interplate magmatism in East China, magmatic evolution, and lithosphere-asthenosphere interactions in the vicinity of Taiwan and Ryukyu subduction-Okinawa backarc system. He is one of the leaders for the

Comprehensive Research on East Asian Tectonic Evolution project.

Isabelle M. Cozzarelli

Research Hydrologist, U.S. Geological Survey

Isabelle Cozzarelli's research contributions to understanding the geochemical effect of organic compounds in aquifers have elucidated the long-term fate of environmental contaminants. Combining careful fieldwork and exacting laboratory analysis, her new insights into the role of electron acceptors in biodegradation of hydrocarbons inform our understanding of toxic substances in groundwater.

Ghislain de Marsily

University of Paris VI

Elected to Fellowship as the 2004 Meinzer awardee.

Cynthia Dusel-Bacon

U.S. Geological Survey

Cynthia Dusel-Bacon is widely recognized in the United States and Canada for her contributions to the geology of the Yukon-Tanana terrane of east central Alaska and to the metamorphic history of the state. She has an outstanding record in publication and professional service.

Carol A. Evenchick

Macdonald Professor of Volcanology, University of Hawaii

Carol Evenchick has brought a multidisciplinary approach to the Bowser basin in the Canadian Cordillera, where she has mapped an area roughly the size of the Swiss

Alps. She has documented a previously unrecognized thrust belt that collapsed the submarine fan and deltaic deposits of the Bowser basin and has demonstrated that it is comparable in structural style and tectonic significance to the more famous foreland thrust belt to the east.

Paul G. Fitzgerald

Associate Professor, Syracuse University

Paul G. Fitzgerald is nominated for Fellowship in recognition of his outstanding contributions to tectonics and long-term landscape development, his application of fission-track and U-Th/He analysis of apatite to these problems, and his outstanding teaching of both undergraduate and graduate students.

Andrew G. Fountain

Associate Professor, Portland State University

Andrew Fountain's detailed work in the Washington Cascade Range and Antarctica's Dry Valleys has resulted in major contributions to understanding glacier hydrology and glacier-climate interactions. His teaching of hydrology, geomorphology, and remote sensing at Portland State University provides an important legacy for the future.

John W. Goodge

Professor, University of Minnesota-Duluth

John Goodge is nominated for his leadership and definitive studies of the tectonic and depositional history of the Ross Orogen in the Transantarctic Mountains, for his coordination and

involvement in international geophysical investigations and mapping of the orogen and adjacent East Antarctic shield, and for his dedication and commitment to both undergraduate and graduate geology education.

William K. Hartmann

Planetary Science Institute
Elected to Fellowship as the 2004 Gilbert awardee.

Rachel M. Haymon

Professor, University of California-Santa Barbara

Rachel Haymon is nominated for her research on interrelationships between hydrothermal, magmatic, tectonic, and biological processes at ocean ridge crests and the time scales and causes of variability in ridge crest hydrothermal systems, as well as for identifying the controls on variations in hydrothermal chemical reactions and the effects of organisms on formation of mineral deposits in these systems.

George M. Hornberger

Professor, University of Virginia

In 123 peer-reviewed articles, three books, innumerable technical reports, myriad reviews, and countless talks, lectures, and conversations, George Hornberger has provided profound insights into the fundamental physical phenomena involved in the occurrence and movement of water in and on Earth's surface. Leadership in publications, contributions as an advisor to federal agencies, and commitment to teaching add to his impact on the community.

Paul A. Hsieh

Research Hydrologist, U.S. Geological Survey

Paul Hsieh has made definitive contributions to the understanding of groundwater in fractured-rock environments. He has also coordinated multidisciplinary research on flow and transport in crystalline rock at Mirror Lake, New Hampshire, an internationally known field site, and served on two NRC committees on flow in fractured rocks, one of which he chaired.

Xiaolong (Bill) Hu

Associate Professor, Florida State University

Xiaolong (Bill) Hu is nominated for development of a novel stochastic theory, numerical methods of moment, for solute transport in a nonstationary flow field, and a sequential self calibration method for inversely estimating a distribution of conductivity field with fields pumping and/or tracer test data. These methods were applied in Yucca Mountain and the Nevada Test Site.

Neil F. Hurley

Boettcher Professor, Colorado School of Mines

Neil F. Hurley has 26 years of professional experience with the petroleum industry and the Colorado School of Mines, where he holds the Charles A. Boettcher Distinguished Chair in Petroleum Geology. He is an international leader in research and technology in reservoir characterization and stratigraphy of carbonate and fractured reservoirs throughout the world. Advances in education and research have been recognized by AAPG, SEPM,

and SPE by his selection as a distinguished lecturer and officer.

Thomas W. Kammer

Professor, West Virginia University

Thomas W. Kammer is worthy of this honor based on his significant record of scientific scholarship and outstanding professional service. Kammer is internationally recognized for his research on Upper Devonian-Lower Mississippian stratigraphy in the Appalachian Basin, paleoecology and community paleoecology of Mississippian crinoids, and systematics of Lower Mississippian crinoids. Kammer also has an exemplary record of professional service to the Paleontological Society.

C. Kent Keller

Professor, Washington State University

Kent Keller has made unique and important contributions to understanding groundwater flow and hydrochemistry in aquitards (till, loess) and basalt aquifers, the role of groundwater in the carbon cycle, and chemical weathering processes in the vadose zone. He mentors students and serves the public through presentations and review responsibilities.

William Berry Lyons

Professor, Ohio State University

William Berry Lyons is nominated for fellowship for his fundamental and outstanding contributions to environmental geochemistry and the study of global change.

GSA Fellows Elected by Council on 15 May 2005

GSA Fellows!

Interested in nominating a colleague, friend, or deserving geoscientist to GSA Fellowship? Please visit www.geosociety.org/members/fellow.htm for **NEW** guidelines and nomination forms.

Questions? Please e-mail awards@geosociety.org or call +1-800-472-1988, ext. 1028, or +1-303-357-1028.

Paul Mann

Senior Research Scientist, University of Texas–Austin
Paul Mann has made major contributions in the fields of tectonics and regional geology. Most of his work has been focused on the circum-Caribbean. In recent years, he has become active in on-land and marine-based studies of the active tectonics of the southwest Pacific. These efforts have involved extensive collaborations with graduate students that have enriched their educational experience at UT Austin.

Eileen P. Poeter

Professor, Colorado School of Mines
Eileen Poeter has been nominated for her original research in groundwater modeling and geophysics and for encouraging collaboration between researchers and practitioners. Contributions include data fusion, accounting for model structure error, use of geophysical and hydraulic data to characterize fractured and multiphase flow, new methods and software to calibrate models and quantify uncertainty, and investigations of heterogeneity.

Robert W. Ritzi, Jr.

Professor, Wright State University
In his research, Robert Ritzi has made fundamental contributions to the understanding of subsurface fluid flow and mass transport. As an educator, he has mentored a large number of successful hydrogeologists who have made important contributions in research and in professional practice. He has provided exemplary service to GSA as chair of the Hydrogeology Division

and through numerous other appointments.

David T. Sandwell

Scripps Institution of Oceanography
Elected to Fellowship as the 2004 Woollard awardee.

George D. Stanley, Jr.

Professor, University of Montana
George D. Stanley is a world leader in the study of fossil corals; his research has shed light on biogeography, reef ecosystem history, and mass extinction. He has served on committees of GSA, SEPM, and the Paleontological Society, and has been honored by the University of Montana for teaching and scholarship.

Edward M. Stolper

California Institute of Technology
Elected to Fellowship as the 2004 Day medalist.

Laura Toran

Associate Professor, Temple University
Laura Toran was elected for new insights into the flow of groundwater in heterogeneous, fractured aquifers, and the chemical evolution of groundwater. Coupling quantitative flow and transport models with geochemical models supported new understanding of the subsurface environment. Her sustained service and commitment to education has advanced the field of hydrogeology.

Janis D. Treworgy

Associate Professor, Principia College
Janis D. Treworgy's research of the Illinois Basin has led to significant contributions to basin development. She is currently teaching

geology to undergraduates. The on-campus discovery of a mammoth skeleton is opening public awareness opportunities and provides a students' hands-on laboratory. She has also been active in the National Association of Geoscience Teachers.

Peter Van Keken

Associate Professor, University of Michigan
Peter Van Keken is a geophysicist who is elected to Fellowship for his fundamental contributions to our understanding of mantle dynamics, including plumes, chemical mixing, slab evolutions, and thermal evolution.

Carol M. Wicks

Associate Professor, University of Missouri
Carol Wicks was elected for her revelatory descriptions of the hydrological and geochemical processes active in karst aquifers. Her work spans field, experimental, and numerical studies that improve our ability to predict groundwater quality and quantity in carbonate terrains. Her leadership in promoting research and education has fostered wider understanding of karst waters.

You-Kuan Zhang

Associate Professor, University of Iowa
You-Kuan Zhang is nominated for fellowship for his significant contributions to hydrogeology and ecohydrology. His work in stochastic analysis of flow and transport in heterogeneous porous media is particularly noteworthy.

Youxue Zhang

Professor, University of Michigan
Youxue Zhang has made important contributions to understanding the distribution and behavior of volatiles in silicates and silicate melts, the kinetics and dynamics of geological processes, the processes of gas-driven eruptions, and the geochemical evolution of Earth.

Chen Zhu

Associate Professor, Indiana University
Chen Zhu is at the forefront of exciting interdisciplinary research in hydrology and geochemistry. He is renowned for his work on the interplay between chemical, physical, and biological processes in Earth's subsurface. His commitment to excellence typifies Fellows of GSA.

GSA Fellows Elected by Council on 15 May 2005

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GSA Celebrates New 50-Year Members for 2005

GSA acknowledges the following people for their 50-year membership in GSA. We appreciate your dedication and loyalty to GSA for all these years! Be sure to find your names listed in GSA's Annual Meeting Hall of Fame in Salt Lake City, 15-19 October 2005.

Donald R. Baker
Manuel N. Bass
Robert Taylor Bean
Charles F. Berkstresser Jr.
Victor Benavides-Caceres
Merwin Bernstein
Philip M. Bethke
Hans Martin Bolli
Manuel G. Bonilla
Lewis T. Braun
Harold K. Brooks
Charles Q. Brown
Henry S. Brown
Randall E. Brown
Kent O. Bushnell
Douglas R. Callier
Albert V. Carozzi
Oran R. Carter
Robert M. Chapman
Earl A. Christiansen
Philip Cohen
Stephen G. Conrad
Richard J. Conrill
Don U. Deere
Fred A. Donath
Hugh H. Doney
Thomas W. Donnelly
F.L. Doyle
Russell R. Dutcher
John R. Dyni
F. Donald Eckelmann
Curtis H. Elder
Alfred G. Fischer

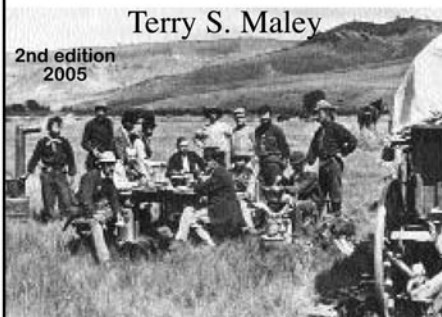
Gerald L. Fletcher
James M. Forgotson Jr.
Robert J. Foster
Maurice G. Frey
Samuel A. Friedman
Donn S. Gorsline
Ralph J. Gray
Seymour S. Greenberg
Allan M. Gutstadt
Robert B. Hall
C. Edgar Hannum
George R. Harlow
Ralph C. Heath
Melvin J. Hill
Roy L. Ingram
William P. Irwin
Marvin E. Kauffman
Frederick L. Klinger
Murray Levish
Donald W. Lovejoy
Robert L. Maby Jr.
William C. MacQuown Jr.
Charles R. Maise
Charles J. Mankin
George E. McGill
Bill J. McGrew
Seymour Merrin
Robert W. Metsger
Daniel Milton
Noriyuki Nasu
Robert B. Nelson
Jack E. Oliver
Alan L. O'Neill

Margaret O. Oros
Earl H. Pampeyan
M. Dane Picard
Ranard J. Pickering
Forrest G. Poole
Donald B. Potter
David Ramaley
Anthony Reso
Frank H. Rhodes
James A. Rhodes
Jack C. Rosenau
Edward T. Ruppel
Ernest E. Russell
Kelvin Norman Sachs
E. Lynn Savage
Cecil J. Schneer
Charles M. Shaw
Marshall K. Shurnas
Sigmund Snelson
Donald S. Stone
Harold B. Stonehouse
Carlton T. Sumsion
Frederick C. Taylor
Richard D. Terry
George Theokritoff
Herbert Tischler
James C. Warman
William W. Webber
Donald R. Wiesnet
Ronald E. Wilcox
John C. Wilson

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fieldgeology@msn.com

2005 Gladys W. Cole and W. Storrs Cole Memorial Research Awards

The 2005 Cole Awards for Postdoctoral Research are funded by the GSA Foundation.

Kenneth Errol Lepper, North Dakota State University, was awarded US\$7,600 from the **Gladys W. Cole Fund** for research in geomorphology of semi-arid and arid terrains for his research project "Fence row dunes as archives of eolian soil erosion rates in west Texas and eastern New Mexico."

Daniela N. Schmidt, University of Bristol, UK, was awarded US\$7,000 from the **W. Storrs Cole Fund** for research in invertebrate micropaleontology for her research project "Rate and mode of morphological diversity in planktonic foraminifers after the K/P extinction."

2005 GSA Research Grants Awarded



The GSA Committee on Research Grants met at GSA Headquarters in Boulder, Colorado, on Saturday, 19 March 2005, and awarded \$500,080 to 326 graduate students. The committee also selected nine alternate candidates in the event that any grantees return all or part of their funds due to a change in their research project or receipt of funds from another source. The sixteen committee members for 2005 were Michael Blum (chair), Laurie Brown, Frank Corsetti, Allen Dennis, Eric Erslev, Martin Goldhaber, Stephen Hasiotis, Stephen Harlan, Vincent Matthews, Charles Nittrouer, Julia Sankey, Robert Shuster, Bruce Simonson, Sorena Sorensen, Lisa Stillings, and Carol Wicks.

The Committee thanks the National Science Foundation (NSF) for its continued support of the Research Grants Program. This is the first year of a new three-year matching grant (ending in 2007); GSA is proud to have had continual NSF support since 1991.

For the first time, the application and review processes were conducted online, and the program was a big success, with a record 720 students applying. Of the 720 students who applied for funding, 326 were awarded a grant (45%). The largest grant was \$3,500; the smallest was \$900. The average grant was \$1,533. Last year, 585 applications were received, and 274 grants were given out (47%). The average grant last year was \$1,742. Although the average grant amount has gone down slightly, the committee was able to fund close to the same percentage as last year. The award range remained the same.

2005 Student Research Grant Statistics

Total proposals received	720
Total proposals funded	326
Total dollars awarded	US\$500,080
Average request	US\$2,505
Average award	US\$1,533

2005 Partial List of Funding Sources

US\$

Joseph T. Pardee Memorial Fund	\$224,000
Partial GSA Funding	\$224,000

Geophysics Division (to augment Cox Award)	\$1,050
Sedimentary Geology Division Award	\$1,000
Structural Geology and Tectonics Division Award	\$3,600
Geophysics Division Grant	\$250
Total Division Funding	\$5,900

Total National Science Foundation Funding*	\$163,900
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Harold T. Stearns Award Fund	\$3,000
Lipman Fund	\$3,900
Blechschmidt Award	\$1,000
Cox Award (Geophysics Division)	\$1,100
Dillon Alaska Award	\$2,300
Reed Research Award	\$1,600
Sisson Research Award	\$2,000
Hydrogeology Division Award	\$2,000
Montagne Fund	\$500
Research Fund	\$8,000
GeoStar	\$6,000
Curtis Fund	\$4,000
Ross Fund	\$2,500
Wanek Fund	\$2,600
Snavelly	\$1,500
Unrestricted	\$40,000
Terman (to be awarded in October)	\$5,000
Memorial Fund	\$15,000
Total GSA Foundation Funding	\$103,400

*NSF grant matched at least 2 to 1 by GSA and GSA Foundation.

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Remember the feeling of pride and accomplishment?
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Outstanding Mentions 2005



The committee has recognized 19 of the proposals as being of exceptionally high merit in conception and presentation. This merit will be formally recognized by GSA at the President's Student Breakfast to be held at the Annual Meeting in Salt Lake City, Sunday, 16 Oct., from 7–8:30 am. At that time, certificates and ribbons will be handed out to the students.

Jake Bailey, University of Southern California, for "Toward an archetypal microbial biofacies regime: Microbial heterotrophy in ancient lakes."

Liselle Batt, University of Idaho, for "Implications of intra-sample variability for interpreting high frequency fluctuations in whole rock derived $\delta^{13}\text{C}$ curves."

Patrick Belmont, Lehigh University, for "Calibrating model for estimating basin-wide erosion rates from in situ terrestrial cosmogenic nuclides."

Cristian Carvajal, University of Texas at Austin, for "The role of sea level, sediment supply and basin physiography on the development of the deepwater sandstones of the Lewis Shale in the Washakie Basin."

Rebecca Carey, University of Hawaii at Manoa, for "Understanding phreatoplinian volcanism: The Askja 1875 eruption."

Nicole Davis, University of Cincinnati, for "Timing and style of glaciation in semi-arid, westerlies-dominated SW Tibet: A test for synchronicity with the Northern Hemisphere ice sheets."

Tracy Fenger, University of North Carolina at Chapel Hill, for "Stable isotopic analysis of the European oyster, *Ostrea edulis*: a calibration for paleoenvironmental reconstruction."

Kurt Frankel, University of Southern California, for "Fault slip rates, paleoseismology, and the constancy of seismic strain release on the Death Valley–Furnace Creek fault zone."

Scott Johnston, University of California–Santa Barbara, for "Multiple metamorphic events during UHP orogenesis: Monazite geochronology of the Hornelen Region, western Norway."

Richard Koehler, University of Nevada–Reno, for "Paleoseismic history of late Quaternary faults in west central Nevada."

Andrew Kylander-Clark, University of California–Santa Barbara, for "Ages and garnet zoning of ultrahigh-pressure eclogites in western Norway: Implications for the closure of the Lu/Hf system in garnet."

Silvia Mancini, University of Toronto, for "Tracking the fate of petroleum hydrocarbon contamination in groundwater."

Christyanne Melendez, Northern Arizona University, for "Debris avalanche event on an isolated rhyolitic dome, Cerro Pizarro, Mexico: Comparative study between small and large scale events."

Joshua Miller, University of Chicago, for "Taphonomic biases of temperate mammalian death assemblages."

James Schiffbauer, Virginia Polytechnic Institute and State University, for "Probable eukaryote fossils preserved in Archean-Paleoproterozoic shales: A new window onto the early biosphere."

Benjamin Schwartz, Virginia Polytechnic Institute and State University, for "A multi-method approach to characterizing sinkhole hydrogeology and recharge mechanisms in agricultural settings."

Jocelyn Turnbull, University of Colorado, for "Quantification of fossil fuel and biomass burning CO₂ emissions from northern China."

Dylan Ward, University of Colorado, for "Quantification of deformation rates in the Alaska Range northern foothills through dating of progressively deformed stream terraces."

Brooke Wilborn, University of Oklahoma, for "Paleobotany of the Morrison and Cloverly formations, Bighorn Basin, Wyoming."

2005 Special Awards



The committee selected recipients of the special awards that are named in honor of the donors or as memorials to former members of the Society.

Gretchen L. Blechschmidt Award

The Gretchen Louise Blechschmidt Award Fund was established for women in the geological sciences who have an interest in achieving a Ph.D. in the fields of biostratigraphy and/or paleoceanography, sequence stratigraphy analysis, particularly in conjunction with research in deep-sea sedimentology, and a career in academic research. The 2005 recipient is **Brooke Wilborn** for "Paleobotany of the Morrison and Cloverly formations, Bighorn Basin, Wyoming."

John T. Dillon Alaska Research Award

The John T. Dillon Alaska Research Award honors the memory of Dillon, who was particularly noted for his

2005 Special Awards



radiometric age-dating work in the Brooks Range, Alaska. Two areas that serve as guidelines for selection of the award are field-based studies dealing with the structural and tectonic development of Alaska and studies that include some aspect of geochronology (either paleontologic or radiometric) to provide new age control for significant rock units in Alaska. The 2005 recipient is **Dylan Ward** for "Quantification of deformation rates in the Alaska Range northern foothills through dating of progressively deformed stream terraces."

Robert K. Fahnestock Award

The Robert K. Fahnestock Award honors the memory of Fahnestock, a former member of the Research Grants Committee, who died indirectly as a result of service on the committee. The grant is awarded for the best proposal in sediment transport or related aspects of fluvial geomorphology, Fahnestock's field. The 2005 recipient is **Patrick Belmont** for "Calibrating model for estimating basin-wide erosion rates from in situ terrestrial cosmogenic nuclides."

Lipman Research Award

The Lipman Research Fund was established in 1993 and is supported by gifts from the Howard and Jean Lipman Foundation. The purpose of the fund is to promote and support student research grants in volcanology and petrology. The president of the Lipman Foundation, Peter W. Lipman, was the recipient of a GSA research grant in 1965. The 2005 recipient is **Christyanne Melendez** for "Debris avalanche event on an isolated rhyolitic dome, Cerro Pizarro, Mexico: Comparative study between small and large scale events."

Bruce L. "Biff" Reed Scholarship Award

The Bruce L. "Biff" Reed Scholarship Fund was established to provide research grants to graduate students pursuing studies in the tectonic and magmatic evolution of Alaska, primarily, and also can fund other geologic research. The 2005 recipient is **Michael Field** for "Structural and kinematic analysis of the Kugruk Fault Zone, Seward Peninsula, Alaska."

Alexander Sisson Research Award

Family members of Alexander Sisson established a fund in his memory to promote and support research for students pursuing studies in Alaska and the Caribbean. The 2005 recipient is **Grant Zazula** for "Paleoecology of Pleistocene fossil arctic ground squirrel middens from eastern Beringia."

Harold T. Stearns Fellowship Award

Stearns established the Harold T. Stearns Fellowship Award in 1973 for student research on aspects of the geology of the Pacific Islands and the circum-Pacific region. This year, the committee presented the award to two candidates:

Denise Giles for "Assimilation of new crust versus recycling of plutonic roots during long-lived volcanism as recorded by $\delta^{18}\text{O}$ at Aucanquilcha volcano, central Chile" and **Nina Triche** for "Systematics and biogeography of fossil and

extant penguins (Aves: *Spheniscidae*), as correlated to Southern Hemisphere tectonic history."

John Montagne Fund

The John Montagne Fund was established in 2000 to support one recipient's research in the field of Quaternary geomorphology. The 2005 recipient is **Nicole Davis** for "Timing and style of glaciation in semi-arid, westerlies-dominated SW Tibet: A test for synchronicity with the Northern Hemisphere ice sheets."

Alexander and Geraldine Wanek Fund

The Wanek Fund was established in 2002 to support research dealing with coal and petroleum resources, mapping, and engineering geology, marine resources, petroleum economics, appraisal, and evaluation, and the geology of phosphate resources. The 2005 recipient is **Jocelyn Turnbull** for "Quantification of fossil fuel and biomass burning CO_2 emissions from northern China."

Charles A. and June R.P. Ross Research Fund

The Ross Research Fund was established in 2002 to support research in the fields of biostratigraphy (including, but not limited to, fossil age dating and the study of evolutionary faunal successions), stratigraphy and stratigraphic correlation, paleogeography and paleobiogeography, interpreting past environments of deposition and their biological significance, and the integration of these research areas into better global understanding of (1) past plate motions (plate tectonics and sea-floor spreading); (2) past sea level events, including their identification and ages; and/or (3) climate changes and effects of those climate changes on Earth's inhabitants through geologic time. There should be, over time, a balance of money among the awards across these various subject subfield categories, depending on the merit of the annual project proposals. The 2005 recipient is **Liselle Batt** for "Implications of intra-sample variability for interpreting high frequency fluctuations in whole rock derived $\delta^{13}\text{C}$ curves."

Parke D. Snavely, Jr., Cascadia Research Award Fund

The Parke D. Snavely, Jr., Cascadia Research Award Fund provides \$1500 to support field-oriented graduate student research that contributes to the understanding of the geologic processes and history of the Pacific Northwest convergent margin, or to the evaluation of its hazard or resource potential. The 2005 recipient is **Kristin Hill** for "Detecting possible magma intrusion at Mount Baker, WA, using renewed gravity surveys."

The Maurice "Ric" Terman Fund

The Maurice "Ric" Terman Fund provides one-year grants to fund the Ph.D. theses and post-doctoral research of East Asian scientists. Countries currently include: Cambodia, China, Indonesia, Japan, Korea, Malaysia, Papua New Guinea, Thailand, and Vietnam. The recipient will be chosen in the fall of 2005.

2005 GSA Research Grants Awarded



A	Brossy, Cooper Brown, Brendan	Ford, Heather Fowler, Kimberly Frankel, Kurt Frost, Edmund Fuentes, Facundo	Jackson, Keith Jaisi, Deb Jamet, Catherine Jewell, Jessica Jin, Lixin Johnson, Katherine Johnston, Scott Johnston, Shelley Jones, Heather
Adelsberger, Katherine Alexander, Jeremy Allen, Ethan Allison, Alivia Al-Suwaidi, Aisha Anderson, Jeffrey Andres, Brian Andrews, Megan Antinao, Jose Luis Aschoff, Jennifer Assam, Jason Atkinson, Rebecca Ault, Alexis Austin, Nicholas Austin, Allison Axford, Yarrow Azouz, April	C	G	K
	Callahan, Owen Carey, Rebecca Carter, Adam Carvajal, Cristian Casey, Michelle Casteel, John Cey, Bradley Cheng, Chih-Hsin Coates, John Collier, Sarah Cotsonika, Laurie Crosby, Christopher Currano, Ellen	Galster, Joshua Galvin, Rachel Garland, Susan Garlick, Sarah Gehman, Carter Gelinias, Amy Ghikas, Constandina Giffin, Joy Giles, Denise Goeke, Elizabeth Gordon, Stacia Gracely, John Grawe, Larisa Gray, Brian Griesel, Gerald Griffin, Randy Gustavson, Jane Guynn, Jerome	Kalk, Michael Kanaya, Taka Kathan, Kasey Katvala, Erik Kaunda, Rennie Kellett, Dawn Kelley, Daniel Keskula-Snyder, Anna King, Daniel Kirk, Matthew Kirwan, Matthew Klochko, Kateryna Knight, Terrell Knight, Charles Koehler, Richard Kraatz, Brian Krenz, Jennifer Kristjansdottir, Greta Bjork Kruckenberg, Seth Kula, Joseph Kylander-Clark, Andrew
B	D	H	L
Badham, Scott Bailey, Jake Ballenger, Jesse Barclay, Richard Barresi, Tony Batt, Liselle Baugh, Heather Beatty, Tyler Becker, Richard Belley, France Belmont, Patrick Benjamin, Michael Benoit, Matthew Berger, Aaron Bhattacharyya, Kathakali Bingham, Patrick Birgenheier, Lauren Bishop, James Black, Jessica Blackburn, Terrence Blecha, Andrea Bonamici, Chloe Bonelli, James Bonilla, Alejandra Boroughs, Scott Boullion, Andre Bowerman, Nicole Boyer, Douglas Brahney, Janice Brand, Brittany Brehm, Andy Brightwell, Stephanie Brocka, Chris	Daigle, Thomas Davies, Maureen Davis, Nicole Davis, Benjamin DeGeest, Amy DeJong, Benjamin Dewane, Terrence Dexter, Troy Diaz Tushman, Kira Didericksen, Brad Diefendorf, Aaron Dilts, Stefanie Dodd, Justin Domrose, Carolyn Dong, Lin Downs, Jason Dressler III, Donald Dumond, Gregory Dunn, Joshua Dyer, Kuwana	Hadder, Kevin Hager, Christian Haines, Samuel Hall, Jonathan Hamblock, Julie Hamilton, Michael Harkins, Sara Harnik, Paul Hartsough, Peter Hartzell, Jeanne Harvey, Mark Harvey, Mary Hawkins, Amber Haynes, Elizabeth Henza, Alissa Hepper, Kristin Hertz, Matthew Herz, Meghan Hill, Kristin Hopkins, Melanie Horsman, Eric Hubbs, Steven Hungerford, Jefferson Hunsinger, Glendon	LaBlanc, Kelly LaMaskin, Todd Lancaster, Robin Lane, Edward Leggett, William Legleiter, Carl Lenarz, William Lennox, Brent Lerch, Derek Letcher, Alice Lewandowski, Sharon Lewis, Dave Linkimer, Lepolt Lipinski, Brian Logan, Brandy Londono, Ana Loope, Henry Lorentz, Nathaniel Lower, Aaron Lugolobi, Festo
	E	J	
	Edwards, Amy Emerson, Lisa Eoff, Jennifer Erdmann, Saskia	Jackson, Frances	
	F		
	Farke, Andrew Febo, Lawrence Fenger, Tracy Fernandez, Adriana Field, Michael Finnegan, Noah Fisher, Christopher		

2005 GSA Research Grants Awarded



Luther, Amy	Needham, Lyndsey		Turnbull, Jocelyn
M	New, Jennifer	S	Turner, Jamey
Macalister, Lucie	Newell, Dennis	Sanders, Heather	U
Macdonald, Francis	Nielsen, Timothy	Scherer, Hannah	Udeze, Chioma
Maga, Ali Murat	Niman, Katie	Schiffbauer, James	V
Mancini, Silvia	Nixon, Chantel	Schiffman, Celia	Van Alstine, Jon
Mann, Crystal	Noto, Christopher	Schopka, Herdis	Vetter, Lael
Manners, Rebecca	O	Schroer, Katherine	W
Marcott, Shaun	Oster, Jessica	Schuneman, Patrick	Wang, Xianfeng
Markwort, Ross	Oxford, Jeremiah	Schwartz, Benjamin	Ward, Dylan
Martens, Uwe	P	Sen, Pragnyadipta	Washington, Gibran
Martin, Ruth	Passey, Benjamin	Serman, Nina	Watanabe, Shizuko
Mason, Maureen	Patrickson, Shela	Sertich, Joseph	Wegmann, Karl
Matson, Samuel	Paul, Christopher	Sessa, Jocelyn	Werning, Sarah
Mattox, Joy	Paulson, Benjamin	Shanahan, Timothy	Werts, Scott
Mayer, Paul	Peppe, Daniel	Shen, Bing	Wilborn, Brooke
Mayer, James	Persico, Lyman	Silva, Juan Carlos	Wilcox, William
McFadden, Kathleen	Peryam, Tom	Smith, Shane	Willard, Pamela
McIntosh, Jennifer	Peterman, Emily	Smith, Jon	Williams, Kelsay
McLeod, Brock	Petrunic, Barbara	Snow, Cameron	Wolf, David
McRivette, Michael	Pinan-Llamas, Aranzazu	Solpuker, Utku	Woody, Daniel
Melendez, Christyanne	Pourmand, Ali	Souders, Amanda Kate	Wysong, Eric
Melzer, Susan	Powers, Lindsay	Spearing, Kurt	Z
Metzger, Christine	Primm, Skylar	Specker, Christina	Zambito, James
Miller, Joshua	Pullen, Alexander	Stevenson, James	Zazula, Grant
Miller, Brett	Q	Stokes, Philip	Zeigler, Kate
Milliken, Kristy	Quazi, Shahida	Stroud, Misty	Zhang, Gengxin
Miner, Michael	Quillmann, Ursula	Sullivan, Walter	Zhu, Liming
Molhoek, Emily Ann	R	Surface-Evans, Sarah	
Montross, Scott	Raterman, Nickolas	Sweet, Dustin	
Moore, Jeffrey	Refsnider, Kurt	T	
Morrissey, Sheila	Reyes, Alberto	Taha, Patrick	
Moscardelli, Lorena	Reynolds, Amanda	Taylor, Joshua	
Mucuta, Dana	Reznik-Jose, Audrey	Taylor, Aron	
Mushkin, Amit	Rivers, John	Tchakirides, Tiffany	
Musselman, Zachary	Robinson, Simon	Terry, Rebecca	
Mutiti, Samuel	Rocke, Benjamin	Tincher, Christopher	
Myers, Nicole		Tipple, Brett	
N		Toprak, Funda	
Natel, Heidi		Tosca, Nicholas	
		Triche, Nina	

Mark Your Calendars for the Annual President's Student Breakfast!

Sunday, 16 October, 7–8:30 a.m., Salt Lake City, Utah

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COMMENTARY

Ice Age Floods National Geologic Trail

New legislation was presented to Congress in January 2005 for a proposed Ice Age Floods National Geologic Trail, to be located over a four-state (Montana, Idaho, Washington, and Oregon) region of the Pacific Northwest. The proposed trail would be managed by the National Park Service (NPS) and use existing public lands to tell the story of the cataclysmic Ice Age floods, beginning with the pioneering work of legendary geologists J Harlen Bretz and Joseph T. Pardee. These men, and many other geologists since, uncovered a fascinating story of repeated outburst floods, mostly from Glacial Lake Missoula, that occurred periodically throughout the Pleistocene. Ice Age floods, moving at up to 80 mph and lasting a week or less, carved a complex network of dry coulees and cataracts, while depositing 400-ft-tall sediment bars—many with giant current ripples. These unique landforms and many more, including misplaced, ice-rafted erratics up to almost 1000 ft above valley floors, occur all along the 700-mile-long route of the floods.

Members of the public and the scientific community are coming together in support of this first-of-its-kind National Geologic Trail, which will span the area between the Clark Fork River of Montana and the mouth of the Columbia River. A grassroots movement began in 1994, when Pacific Northwest geologists and interested citizens joined forces to organize the Ice Age Floods Institute (IAFI), a nonprofit educational organization dedicated to bringing the story of repeated cataclysmic floods to the public. In 1999, the NPS, recognizing the significance of these obscure events, commissioned an environmental assessment and study of alternatives to tell the story of the floods. The recommendation for an Ice Age Floods National Geologic Trail came as a result of the NPS and IAFI study. The study called for the NPS to coordinate with the IAFI as well as state and local governments, public, tribal, and private interpretive efforts to tell a cohesive story.

Recently, the National Geologic Trail idea has received widespread bipartisan support and attention of legislators from the Pacific Northwest delegation. Two separate bills were introduced to each house of Congress calling for adoption of an Ice Age Floods National Geologic Trail. Congressman Doc Hastings (R-Wash.) introduced the bill to the House, while Maria Cantwell (D-Wash.) introduced it to the Senate. This “park without boundaries” would include kiosks and signs placed on the existing network of public lands and roadways that pass through the floods region. Wording in the bills limits purchase or donation of private property from assenting landowners to 25 acres or less.

The region could reap tremendous socioeconomic benefits from such a trail with relatively little capital expenditure. A National Geologic Trail would attract interested parties from around the region as well as across the country. The benefits

from tourism and development would bring a much-needed boost to rural economies along the floods route. The trail would not only increase public awareness and appreciation of their geologic heritage, but also inspire young minds—perhaps providing a catalyst for a new generation of earth scientists.

The Ice Age Floods National Geologic Trail bill awaits debate in Congress, which could happen soon. Those members of the geologic community in favor should write their U.S. Congressman promptly, informing them of the bill and expressing their support. This could be just the beginning in a series of National Geologic Trails; certainly many other parts of the nation are just as deserving and have their own stories to tell.

To view the NPS Ice Age Floods Study of Alternatives and Environmental Assessment go to www.nps.gov/iceagefloods. For more information on the Ice Age Floods Institute and Ice Age Floods National Geologic Trail legislation visit www.iceagefloodsinstitute.org.

Bruce Bjornstad, *Lake Lewis Chapter, IAFI Licensed Geologist/Hydrogeologist Senior Research Scientist, Pacific Northwest National Laboratory*

Photos taken in eastern Washington State by Bruce Bjornstad. **Top:** an ice-rafted granodiorite erratic near the Columbia River. **Bottom:** Frenchman Coulee in the Channeled Scabland.



Call for Geological Papers

2006 GSA Section Meetings

SOUTH-CENTRAL SECTION

6-7 March 2006
University of Oklahoma
Norman, Oklahoma

Abstract Deadline: 9 December 2005

Information: Neil Suneson, Oklahoma Geological Survey, University of Oklahoma, 100 E Boyd St., Rm N131, Norman, OK 73019-0628, +1-405-325-3031, nsuneson@ou.edu

NORTHEASTERN SECTION

20-22 March 2006
Radisson Penn Harris Hotel and Convention Center
Camp Hill/Harrisburg, Pennsylvania

Abstract Deadline: 13 December 2005

Information: Noel Potter, Dickinson College, Dept. of Geology, Carlisle, PA 17013-2896, +1-717-245-1340, pottern@dickinson.edu

SOUTHEASTERN SECTION

23-24 March 2006
Marriott Hotel
Knoxville, Tennessee

Abstract Deadline: 5 January 2006

Information: Claudia Mora, University of Tennessee, Dept. of Earth and Planetary Sciences, 1412 Circle Drive, Knoxville, TN 37996-1410, +1-865-974-5499, cmora@utk.edu

NORTH-CENTRAL SECTION

20-21 April 2006
Student Center, University of Akron
Akron, Ohio

Abstract Deadline: 25 January 2006

Information: John Szabo, Dept. of Geology, University of Akron, Akron, OH 44325-4101, +1-330-972-8039, jpszabo@uakron.edu

CORDILLERAN SECTION

(Joint Meeting with PSAAPG and SPE-A)

8-10 May 2006
University of Alaska
Anchorage, Alaska

Abstract Deadline: 2 February 2006

Check future issues of *GSA Today* for more information.

ROCKY MOUNTAIN SECTION

17-19 May 2006
Western State College
Gunnison, Colorado

Abstract Deadline: 21 February 2006

Information: Rob Fillmore, Western State College, Dept. of Natural and Environmental Sciences, Gunnison, CO 81231-0001, +1-970-943-2092, rfillmore@western.edu

The Kerry Kelts Research Awards of the Limnogeology Division

The application process for the Kerry Kelts Research Awards of the Limnogeology Division is now open. These awards are named in honor of Kerry Kelts, a visionary limnogeologist and inspiring teacher. Up to three awards of \$300 each for use in research related to limnogeology, limnology, and paleolimnology are available. Application for this award is simple and consists of a summary of the proposed research, its significance, and how the award will be used (five-page maximum). Please send your summary in PDF format along with your name and associated information to the chair of the Limnogeology Division, Thomas C. Johnson, tcj@d.umn.edu. **Application Deadline: 10 August 2005.** Awards will be announced at the Limnogeology Division Business Meeting and Reception at the 2005 GSA Annual Meeting in Salt Lake City in October.

We hope to increase the amount of the awards in succeeding years. If you are interested in supporting this awards program, please send your donations, designated for the Kerry Kelts Research Awards of the Limnogeology Division, to GSA Foundation, P.O. Box 9140, Boulder, CO 80301-9140, USA.

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Second Call for GSA Committee Service

Stimulate **Growth** and *Change* Serve on a GSA Committee!

Most committee terms are for three years and begin 1 July 2006 (exceptions are noted below with their respective committees); student representatives serve for two years.

2006–2007 Committee Vacancies

GSA is seeking candidates to serve on Society committees and as GSA representatives to other organizations. Contribute to our science by volunteering or nominating others you think should be considered for any of the following openings. Younger members are especially encouraged to become involved in GSA activities. *Graduate students are eligible to serve on GSA committees as full members, and Council encourages you to volunteer or nominate others for committee service.* Whether you volunteer or make recommendations, please give serious consideration to the specified qualifications for serving on a particular committee. **Please be sure that your candidates are GSA Members or Fellows and that they fully meet the requested qualifications.**

The online nomination form and instructions are available at www.geosociety.org/aboutus/commtees. Click on the **2006–2007 Nomination Form** link to access the form. If you prefer, you may download and complete and fax the paper nomination form, also located at this site. Questions may be directed to Ruth Harrison, rharrison@geosociety.org.

For further details regarding nominating or volunteering for GSA committee service, please refer to the June 2005 issue of *GSA Today*.

Annual Program Committee (AM, B/E, T/E)—4-year terms

Two vacancies: one member-at-large; one councilor or former councilor

Develops long-range plan for increasing the quality of the annual and other Society-sponsored meetings in terms of science, education, and outreach. Evaluates annual meeting technical and scientific programs. **Qualifications:** broad familiarity with different disciplines, previous program experience, or active involvement in applying geologic knowledge to benefit society and raising awareness of critical issues.

Arthur L. Day Medal Award (T/E)

Two member-at-large vacancies

Selects candidates for the Arthur L. Day Medal Award. **Qualifications:** knowledge of those who have made “distinct contributions to geologic knowledge through the application of physics and chemistry to the solution of geologic problems.”

Education (AM, T/E)—4-year term

One graduate-level educator vacancy

Stimulates interest in the importance and acquisition of basic knowledge in earth sciences at all levels of education and promotes the importance of earth science education to the general public. **Qualifications:** ability to work with other interested scientific organizations and science teacher groups to develop precollege earth science education objectives and initiatives.

Geology and Public Policy (AM, B/E, T/E)

Two member-at-large vacancies

Translates knowledge of earth sciences into forms most useful for public discussion and decision making. **Qualifications:** experience in public policy issues involving the science of geology; ability to develop, disseminate, and translate information from the geologic sciences into useful forms for the general public and for GSA members; familiarity with appropriate techniques for the dissemination of information.

Honorary Fellows (T/E)

Two member-at-large vacancies

Selects candidates for Honorary Fellows, usually non–North Americans. **Qualifications:** knowledge of geologists throughout the world who have distinguished themselves through their contributions to the science.

Joint Technical Program Committee (T/E)

Three vacancies: two environmental geoscience representatives; one public policy representative (terms begin 1 Jan. 2007)

Assists in finalizing the annual meeting technical program: reviews abstracts or provides names of reviewers to evaluate abstracts, participates in Web-based activities in the selection and scheduling of abstracts, participates in Topical Session proposal review. **Qualifications:** must be familiar with computers and the Web, be a specialist in one of the specified fields, and be available in mid to late July for the organization of the electronic technical program.

July 2006 Committee Vacancies • *Extensive time commitment required • AM—Meets at Annual Meeting
B/E—Meets in Boulder or elsewhere • T/E—Communicates by phone or electronically

Membership (B/E)

Two vacancies: one member-at-large (government employment category); one student representative (two-year term)

Evaluates membership benefits and develops recommendations that address the changing needs of the membership and attracts new members.

Qualifications: experience in benefit, recruitment, and retention programs is desired.

Minorities and Women in the Geosciences (AM)

Two member-at-large vacancies

Stimulates recruitment and promotes positive career development of minorities and women in the geoscience professions. **Qualifications:** familiarity with minority and women's education and employment issues; expertise and leadership experience in such areas as human resources and education desired.

Nominations (B/E, T/E)

Two member-at-large vacancies

Recommends to Council nominees for the positions of GSA Officers and Councilors, committee members, and Society representatives to other permanent groups.

Qualifications: familiarity with a broad range of well-known and highly respected geological scientists.

Penrose Conferences and Field Forums (T/E)

Two member-at-large vacancies

Reviews and approves Penrose Conference proposals and recommends and implements guidelines for the success of the conferences. **Qualifications:** past convener of a Penrose Conference or Field Forum.

Penrose Medal Award (T/E)

Two member-at-large vacancies

Selects candidates for the Penrose Medal Award. Emphasis is placed on "eminent research in pure geology, which marks a major advance in the science of geology." **Qualifications:** familiarity with outstanding achievers in the geosciences that are worthy of consideration for the honor.

Professional Development (T/E)

One member-at-large vacancy

Directs, advises, and monitors GSA's professional development program, reviews and approves proposals, recommends and implements guideline changes, and monitors the scientific quality of courses offered.

Qualifications: familiarity with professional development programs or adult education teaching experience.

Publications (AM, B/E, T/E)—4-year terms

Two vacancies: one member-at-large; one councilor

Nominates candidates for editor positions, approves editorial boards, reviews the quality and health of Society publications, and explores the initiation of new

ventures, including electronic publishing. **Qualifications:** extensive publications experience.

Research Grants* (B/E)

Five member-at-large vacancies; one NSF delegate

Evaluates student research grant applications and selects grant recipients. **Qualifications:** should have experience in directing research projects and in evaluating research grant applications.

Treatise on Invertebrate Paleontology Advisory Committee (AM)

One member-at-large vacancy (paleontologist)

Advises Council, the Committee on Publications, and the *Treatise* editor in matters of policy concerning this publication. **Qualifications:** must be a paleontologist.

Young Scientist Award (Donath Medal) (T/E)

Two member-at-large vacancies

Committee members investigate the achievements of young scientists who should be considered for this award and make recommendations to Council. **Qualifications:** should have knowledge of young scientists with "outstanding achievement(s) in contributing to geologic knowledge through original research which marks a major advance in the earth sciences."

GSA Representatives to Other Organizations

GSA Representatives to the American Association for the Advancement of Science (AAAS)

Three section representative vacancies: Section E—Geology and Geography; Section W—Atmospheric and Hydrospheric Sciences; Section X—Societal Impacts of Science and Engineering

Must be a member of the AAAS or be willing to join. Must represent the appropriate section background.

Liaison to the U.S. National Committee on Soil Science (USNC/SS)

One liaison vacancy

Should be a soil scientist and GSA member.



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**July 2006 Committee Vacancies • *Extensive time commitment required • AM—Meets at Annual Meeting
B/E—Meets in Boulder or elsewhere • T/E—Communicates by phone or electronically**



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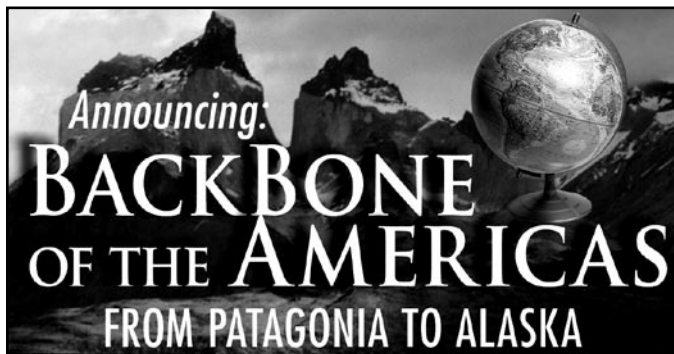
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3-7 April 2006 • Mendoza, Argentina

Backbone of the Americas: From Patagonia to Alaska is a GSA special meeting cosponsored with the Asociación Geológica Argentina. The principal themes are ridge collision, shallow subduction, and plateau uplift along the Americas. Field trips are planned to Patagonia before and the Chilean flat-slab or Central Andean Puna plateau after the meeting. Suzanne Kay and Victor Ramos are serving as meeting co-chairs.

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See www.geosociety.org/meetings/06boa/ for details and to sign up for e-news.

Nominate Your Next Officers and Councilors!

Nominations Accepted until 1 August 2005

The GSA Committee on Nominations requests nominations for officers (vice president and treasurer) and councilors to serve on GSA Council beginning in 2006. Each nomination should be accompanied by basic data and a description of the qualifications of the individual for the position recommended.

The online nomination form is available at www.geosociety.org/aboutus/commtees/, or you may send materials for officer and councilor nominations to Ruth Harrison, GSA, P.O. Box 9140, Boulder, CO 80301-9140, rharrison@geosociety.org.



GSA Foundation Receives a Very Special Bequest



GSA Foundation received a very special bequest this year. Lee Gladish, former Books and Maps coordinator for GSA and associate editor of *GSA News & Information*, left a sizable portion of his estate to the Foundation.

Gladish's gift of cash and his Boulder home totaled over \$550,000 and is the fourth largest bequest in GSA's history. This gift is significant not only because of the amount, but also because it came from a former member of GSA's staff who had high regard for the Society. His bequest follows in the footsteps of R.A.F. Penrose, Joseph T. Pardee, and John F. Mann, three important benefactors of GSA and the Foundation.

Gladish passed away in May 2004 at his home in Boulder. He earned his bachelor's degree (*cum laude*) in journalism

from the University of Minnesota and gained experience in all facets of publishing as head of the publications unit of the Western Interstate Commission for Higher Education from 1961–1976. He came to GSA in 1980 and retired in 1991. He designed many of the covers for GSA books, as well as publications advertisements. At the time of his retirement in 1991, he had worked on several of the *Decade of North American Geology* (DNAG) books. It is most appropriate that a portion of his bequest supports the final DNAG map, the 2005 *Geologic Map of North America*. Program support for GeoCorps™ America in fiscal year 2006 will also come from this gift.



Most memorable early geologic experience:

With Robert Nichols of Tufts College in the summer of 1940, we climbed to the crater rim of Capulin Cinder Cone in NE New Mexico. The huge, spherical volcanic bombs there offered an inviting challenge to roll them down the cone's sides. We earned our Master's of Rock Rolling degrees whenever our bombs rolled the farthest. The practice, however, of lying flat and pushing with our feet quickly ceased when objecting scorpions swarmed out around our legs.

—Sidney E. White

Sarah Andrews, famous mystery writer, is developing something new for the Foundation in association with the Silent Auction. More clues to this mystery will follow in the next issue of *GSA Today*.



GSA FOUNDATION

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GSA MEMORIALS: HELP US REMEMBER



Every year, GSA publishes a memorial volume devoted to deceased GSA members. Memorials are written by associates, friends, or relatives of those who have passed away. Each memorial enables us all to learn more about the fascinating individuals who have been part of GSA.

If you would like to honor a friend or colleague with a memorial, please send your write-up as a Microsoft Word-compatible file via e-mail to awards@geosociety.org. The text should be limited to about 2,000 words and include a selected bibliography of the decedent's works in the earth sciences. Published memorials also include a photo, so

please send a picture of the person you are memorializing, either as a high-resolution jpg attached (as a separate file) to your e-mail or a glossy photograph sent via post. The complete guidelines for compiling your memorial can be found at www.geosociety.org/grants/.

Memorialists and family members of the deceased receive complimentary copies of the memorial before it is included in the bound, published volume.

The following is a list of GSA members who have passed away since 2003. Asterisks signify that a memorial has already been published or is being written for 2005.

Alan Bailey	John A. Fortescue	Barney C. McCasland Jr.	Peter B. Smoor
Roy A. Bailey*	Ted H. Foss*	Digby Johns McLaren	Parke D. Snively Jr.
Thos. D. Barber	Sidney S. Galpin	Thad G. McLaughlin*	Ronald K. Sorem
Allan P. Bennison	Rudolf A. Gees	Wilton N. Melhorn	Robert C. Speed*
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GEOLOGIC PAST

Highlighting Articles from Past Issues of *GSA Bulletin*: 95 Years Ago

PALEOGEOGRAPHY PUT ON THE MAP

GSA Bulletin, February 1910

Charles Schuchert: *Paleogeography of North America*

In a thorough discussion of paleogeography, Charles Schuchert provides *GSA Bulletin* readers (v. 20, p. 427–606) with a new geologic time table (p. 601) and over 50 plates illustrating geologic time periods and the associated formations and faunal changes in North America. His paper begins with a definition of paleogeography as “the geography of geologic time” (p. 431) and gives a history of the science. Beginning with James D. Dana’s 1863 book, *Manual of Geology*, Schuchert presents an overview of early paleogeographic maps. Schuchert directs the reader to Austrian paleontologist M. Neumayr’s 1883 paper on climatic zones in the Jurassic and Cretaceous, which, Schuchert says, “includes what is probably the first paleogeographic map of the world” (p. 432), as well as a discussion of the distribution of marine Jurassic fossils, “on the basis of which,” states Schuchert, “[Neumayr] conceived the great transverse continent of Gondwana” (p. 432). After his thorough account of the history of paleogeography, Schuchert illustrates the shallow continental seas of Paleozoic time in North America (p. 438 and plate 48), giving descriptions and history of the study of each sea. He also writes definitively that “fossils [are] indicative of exact time” in geologic formations (p. 439). Notably, Schuchert collected his first fossil as a teen nearly 38 years before this seminal paper (p. 429).

Charles Schuchert (1858–1942) first presented this paper to GSA at the annual meeting in Baltimore, Maryland, on Dec. 30, 1908. Schuchert, whose formal education did not even include a high school diploma (Cooper, 1999), was chair of Yale University’s geology department from 1909 to 1921, President of GSA in 1922, and recipient of the GSA Penrose Medal in 1934. He is considered one of America’s premier paleontologists, for whom the Paleontological Society named their Charles Schuchert medal in 1973.

REFERENCE CITED

Cooper, C., 1999, Academic genealogy of Brown University’s Planetary Geology Group: <http://www.planetary.brown.edu/~cooper/genealogy/schuchert.html> (Accessed Feb. 24, 2005).

WHEN THE CONTINENTS CREPT AWAY

GSA Bulletin, June 1910

Frank Bursley Taylor: *Bearing of the Tertiary Mountain Belt on the Origin of the Earth’s Plan*

American geologist Frank Bursley Taylor first presented his ideas on the movement of the continents in abstract and lecture form at the GSA Annual Meeting in Baltimore, Maryland, on Dec. 29, 1908. In the subsequent 1910 *GSA Bulletin* (v. 21, p. 179–226) article, Taylor writes what some consider the first-ever discussion of continental drift. Basing much of his argument on the extent and uniformity of “a great world-belt ... of Tertiary fold-mountains almost encircling the earth” (p. 179) and on the work of Eduard Suess, Taylor states that “North America, like Eurasia, had been affected in Tertiary times by a crustal movement” (p. 204). Referring to a bathymetric chart accompanying the text (plate 4), Taylor points to the mid-Atlantic ridge as one of the “most remarkable and suggestive objects on the globe” (p. 216), “a submerged mountain range of a different type and origin from any other on the earth...” (p. 217), by which he supports his theory that the continents separated in Tertiary time (p. 216–217). The mid-Atlantic ridge, in Taylor’s view, “marks the original place of the great fracture” from which “the continents on opposite sides ... crept away” (p. 218).

Incorporating study of the coasts of continents to support his theory, Taylor points to “the remarkable relation of Greenland to North America,” as further evidence that “North America moved toward the southwest” (p. 205). Noting specifically the parallel relationship of the coasts of Greenland and Labrador, he writes, “The parting of these shores can hardly be more recent than the Tertiary” (p. 208). In his observations of Africa, he states “there are many bonds of union which show that Africa and South America were formerly united” (p. 218).

Frank Bursley Taylor (1860–1938) published a follow-up article, titled “Correlation of Tertiary mountain ranges in the different continents,” in *Bulletin* in 1930 (v. 41, p. 431–473), in which he continued to support his theory of the “horizontal sliding of continental crust-sheets.”

ANNOUNCEMENTS

MEETINGS CALENDAR

2005

-
- 18–22 July 4th Annual GML Days 2005, Geography mark-up language and Geo-Spatial Web Services for GIS Conference, Vancouver, British Columbia, Canada. **Information:** www.gmldays.com, +1.604.484.2750, or info@gmldays.com.
-
- 18–29 July International Association of Geomagnetism and Aeronomy, IAGA 2005 Scientific Assembly, Toulouse, France. **Information:** cnfgg@eost.u-strasbg.fr, +33.3.88.450191, fax +33.3.88.603887.
-
- 31 July–5 Aug. Gordon Research Conference (GRC) Metals in Ore-Forming Systems: Sources, Transport, Deposition, Andover, New Hampshire, USA. **Information:** www.grc.uri.edu/programs/2005/inorgeo.htm.
-
- 9–12 August 9th International Conference on Diffuse Pollution, Johannesburg, South Africa. **Information:** www.iwa-wisa-2005.com.
-
- 23–27 August Quaternary Research Association (UK), Conference on Glacial Sedimentary Processes and Products, University of Wales, Aberystwyth, UK. **Information:** <http://qra.org.uk/meet.html#glacial>.
-
- 11–14 September 22nd Annual Meeting of the Society for Organic Petrology (TSOP), Louisville, Kentucky, USA. **Information:** James Hower, +1.859.257-0261, fax +1.859.257.0360, hower@caer.uky.edu, <http://igs.indiana.edu/tsop2005>.
-
- 11–16 September Uranium Mining and Hydrogeology IV, Freiberg, Germany. **Information:** www.geo.tu-freiberg.de/umh/index.htm.
-
- 19–23 September 14th Meeting of the Association of the European Geological Societies, Torino, Italy. **Information:** www.maegs14.com.
-
- 8–13 October American Institute of Professional Geologists 42nd Annual National Meeting, Lexington, Kentucky, USA. **Information:** Tom Spalding, +1.502.458.1209, aipg2005@yahoo.com, www.professionalgeologist.org.
-
- 2–3 November Groundwater under the Pacific Northwest: Integrating Research, Policy, & Education 2005 Conference, Stevenson, Washington, USA. **Information:** State of Washington Water Research Center, watercenter@wsu.edu, +1-509-335-5531, www.swwrc.wsu.edu/conference2005/.

2006

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- 8–9 February Oil and Gas Habitats of Russia and Surrounding Regions, The Geological Society, London, UK. **Information:** Lucy Kimber, The Geological Society, +44 (0)20.7434.9944, fax +44 (0)20.7494.0579, lucy.kimber@geolsoc.org.uk.
-
- 3–7 April Backbone of the Americas—Patagonia to Alaska, Mendoza, Argentina. Co-convened by Asociación Geológica Argentina and GSA. **Information:** Deborah Nelson, dnelson@geosociety.org, +1.303.357.1014, www.geosociety.org/meetings/06boa/index.htm.
-
- 2–7 July Australian Earth Sciences Convention 2006, Geological Society of Australia 18th Australian Geological Convention and Australian Society of Exploration Geophysicists 18th International Geophysical Conference and Exhibit, Melbourne, Australia. **Information:** www.earth2006.org.au.
-
- 16–21 July Zeolite '06: The 7th International Conference on the Occurrence, Properties, and Utilization of Natural Zeolites, Socorro, New Mexico, USA. **Information:** Robert S. Bowman, New Mexico Institute of Mining & Technology, bowman@nmt.edu, www.ees.nmt.edu/Zeolite06.
-
- 26–27 August 4th International Gemological Symposium, GIA Gemological Research Conference, San Diego, California, USA. **Information:** James E. Shigley, +1.760.603.4019, gemconference@gia.edu, www.gia.edu/newsroom/608/21821/news_release_details.cfm.

Visit www.geosociety.org/calendar/ for a complete list of upcoming geoscience meetings.

About People

GSA Fellow **Brian F. Atwater** was named to *Time* magazine's "Time 100," their annual list of "the world's most influential people," published 10 April 2005. Atwater, who is with the U.S. Geological Survey, was recognized for his study of past tsunamis in the Cascadia subduction zone. Atwater is an invited Pardee Keynote Symposia speaker at the 2005 GSA Annual Meeting in Salt Lake City, where he will present the 2004 South Asian Tsunami Pardee Symposium (P1) along with GSA Fellow Joanne Bourgeois of the University of Washington.

The Geological Society (London) presented its 2005 awards at its annual President's Day Meeting on the 18th of May. Among the award recipients were several GSA members. GSA Senior Fellow **Ursula Bailey Marvin** received the Sue Tyler Friedman award for her

distinguished contribution to the recording of the history of geology. Marvin was recognized with GSA's History of Geology Award in 1986. GSL awarded GSA Member **Peter Dominic Clift** with the Murchison Fund, which rewards noteworthy published research in the earth sciences. GSA member **David Gwyn Roberts** and GSA Fellow **Michael Brown** each received GSL's Major Coke Award for significant contributions to the science of geology as well as service to the geoscience community.

GSA Senior Fellow **Samuel S. Adams** was presented with the American Institute of Professional Geologists' 2004 Outstanding Achievement Award. Along with his service to other societies (AGI, SEG, and AAPG among others) Adams has served on numerous GSA committees and on Council, and received the GSA Distinguished Service Award in 2002.

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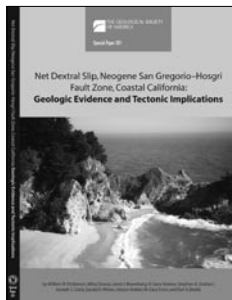
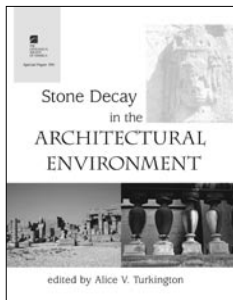
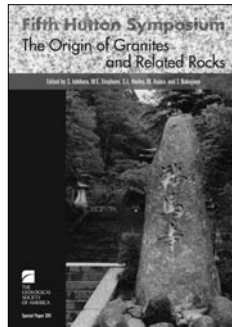
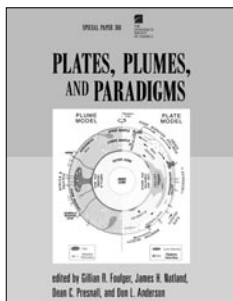
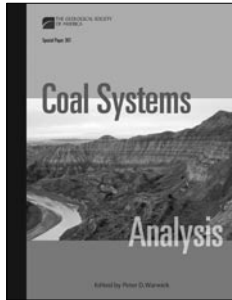
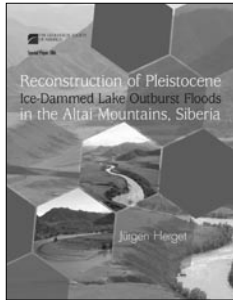
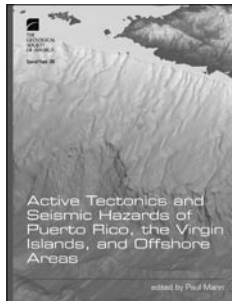
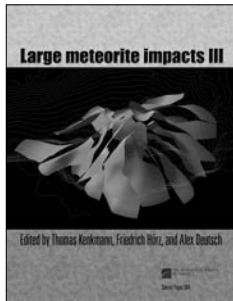
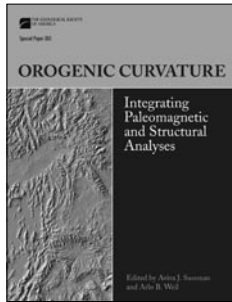
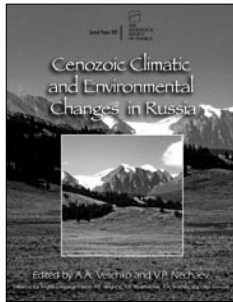
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Cenozoic Climatic and Environmental Changes in Russia *edited by A.A. Velichko and V.P. Nechaev (editors of the English-language edition are H.E. Wright Jr., T.A. Blyakharchuk, A.A. Velichko, and Olga Borisova)*

Today, the vast expanse of Russia, from Western Europe to the Pacific Ocean and from the Arctic Ocean to the countries of Central Asia, has mostly a strong continental climate, with maritime influence in the Far East. But through the Paleogene and Neogene, the great transgression of the Tethys and Paratethys seas expanded from the Mediterranean region northward over the West Siberian lowlands to the Arctic Ocean, bringing with them fluctuating subtropical and warm-temperate climatic conditions, as reconstructed from plant and animal fossils and other paleoclimatic proxies. A cooling trend in the Pliocene culminated in the Quaternary with repeated advances of the Scandinavian ice sheet west of the Ural Mountains, along with the development of permafrost and deposition of loess beyond the ice sheet and over much of Siberia. Compilation of isotopic and microfossil data from the bordering oceans expands the geographic scope of the paleoclimatic reconstructions. This book, translated from a Russian volume published by the Russian Academy of Sciences, Institute of Geography, summarizes the paleoclimatic aspects of the geologic and paleontologic records from ten different areas in Russia and provides quantitative estimates for the repeated changes in temperature and precipitation for the past 65 million years.

SPE382, 226 p., ISBN 0-8137-2382-5
\$70.00, **member price \$56.00**

Orogenic Curvature: Integrating Paleomagnetic and Structural Analyses

edited by Aviva J. Sussman and Arlo B. Weil

Most active and ancient orogenic systems display salients and recesses with varying degrees of curvature in map view. Within these arcuate orogens, many observations (e.g., out-of-plane strains, oblique slip, earthquake swarms, vertical-axis rotations) indicate that material is transported (or flows) in three dimensions, such that no single cross section can fully describe the motion. Although our conceptualization of the architecture of curved mountain belts has become increasingly sophisticated, many questions as to the kinematics and mechanics of forming arcuate orogenic systems still need to be answered. To this end, GSA Special Paper 383 brings together several investigations that integrate structural and paleomagnetic techniques. Examples of the multidisciplinary research presented in the volume include: the impact that vertical-axis rotations have on shortening estimates; magnetic anisotropy and strain distribution as a function of basement/cover decoupling; remagnetization and structural growth; mantle-lithosphere delamination caused by plate bending; and the relationship between shear zones and vertical-axis rotations.

SPE383, 258 p. plus index, ISBN 0-8137-2383-3
\$80.00, **member price \$64.00**

Large Meteorite Impacts III

edited by Thomas Kenkmann, Friedrich Hörz, and Alex Deutsch

The third volume of the series "Large Meteorite Impacts" provides an updated and comprehensive overview of modern impact crater research. In 26 chapters, more than 90 authors from Europe, the United States, Russia, Canada, and South Africa give a balanced, firsthand account of the multidisciplinary field of cratering science, with reports on field studies, geophysical analyses, and experimental and numerical simulations. Nine chapters focus on structure, geophysics, and cratering motions of terrestrial craters. Recent advances in impact ejecta studies and shock metamorphism are assembled, each with seven chapters, and three chapters extend the scope from a terrestrial to a planetary perspective.

SPE384, 457 p. plus index, ISBN 0-8137-2384-1
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www.geosociety.org

Active Tectonics and Seismic Hazards of Puerto Rico, the Virgin Islands, and Offshore Areas

edited by Paul Mann

Puerto Rico and the Virgin Islands occupy a 450-km-long and 300-km-wide segment of the seismically active North America–Caribbean plate boundary zone. Geologic and seismological information on both onland and offshore plate boundary faults are critical for understanding the earthquake and tsunami hazards that these structures pose to a rapidly urbanizing island population of about 4 million inhabitants. This volume presents an integrated set of 15 chapters on the geological, geophysical, and seismological nature of late Quaternary plate boundary zone faults revealed by both onland and offshore studies. The volume chapters are grouped into four sections: (1) three introductory chapters establishing the regional tectonic setting of Puerto Rico and the Virgin Islands and its offshore area using GPS-based geodesy and regional geologic information; (2) three chapters on the instrumental and historical seismicity of the region; (3) five chapters on the identification of late Quaternary faults in Puerto Rico and its shallow coastal areas using onland mapping, fault trenching, and offshore geophysical mapping; and (4) four chapters on seismic sources, ground amplification, and paleoliquefaction.

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Reconstruction of Pleistocene Ice-Dammed Lake Outburst Floods in the Altai Mountains, Siberia

by Jürgen Herget

In the Altai Mountains, located in southern Siberia, some of the largest floods in Earth's history occurred in Pleistocene times. The floods were caused by ice-dammed lake outburst floods comparable with glacial Lake Missoula events. In this volume, the remnants of the repeated jökulhlaups and key features of the local Pleistocene environment are described in review. The volume also focuses on the paleohydraulic interpretation of the traces of the floods to reconstruct their magnitudes and characteristics. Herget applied several established methods in the study as well as developed and applied new approaches (e.g., hydraulic interpretation of run-up sediments, fluvial gravel dunes and local scour around obstacles).

SPE 386, 117 p., ISBN 0-8137-2386-8
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Coal Systems Analysis

edited by Peter D. Warwick

Coal is an important and required energy source for today's world. Current rates of world coal consumption are projected to continue at approximately the same (or greater) levels well into the twenty-first century. This collection of papers provides an introduction to the concept of coal systems analysis and contains examples of how coal systems analysis can be used to understand, characterize, and evaluate coal and coal gas resources. Coal systems analysis incorporates the various disciplines of coal geology to provide a complete characterization of the resource.

SPE387, 111 p., ISBN 0-8137-2387-6
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Fifth Hutton Symposium: The Origin of Granites and Related Rocks

edited by S. Ishihara, W.E. Stephens, S.L. Harley, M. Arima, and T. Nakajima

Granitic rocks are the most important component of Earth's upper continent crust, but their origin remains a topic of considerable debate. Recent developments have underscored the importance of modeling physical and chemical processes as well as the application of field techniques. The Fifth Hutton Symposium on the Origin of Granites and Related Rocks was held in Toyohashi, Japan, in September 2003 to review current thinking on this age-old debate. Some 27 invited papers are collected in this volume and represent all principal areas of research activity. The volume includes papers describing unifying models and new paradigms consistent with recent research, and contributions span the range from anatexis to emplacement and late-stage mineralization. A significant feature of this particular volume is the major contribution by scientists from the Far East both to generic aspects of granite magmatism and to studies of regional importance.

SPE 389, 392 p., ISBN 0-8137-2389-2
\$95.00, **member price \$76.00**

Stone Decay in the Architectural Environment

edited by Alice V. Turkington

Some structures are constantly under threat from natural and human-induced decay processes, yet stone buildings, structures, and works of art remain a permanent feature in our cultural heritage. This volume presents recent research by an international group of geologists and geomorphologists on stone decay in the architectural environment, and it updates the latest theoretical and methodological advances in this field. The volume will be informative to earth scientists concerned with rock weathering in natural and urban locales, and it will be of benefit to those conservators, practitioners, scientists, and students whose interest lies at the interface between research and its application.

SPE390, 61 p., ISBN 0-8137-2390-6
\$45.00, **member price \$36.00**

Net Dextral Slip, Neogene San Gregorio–Hosgri Fault Zone, Coastal California: Geologic Evidence and Tectonic Implications

by William R. Dickinson, Mihai Ducea, Lewis I. Rosenberg,

H. Gary Greene, Stephan A. Graham, Joseph C. Clark, Gerald E. Weber, Steven Kidder, W. Gary Ernst, and Earl E. Brabb

The San Gregorio–Hosgri fault is the major subsidiary strand of the San Andreas fault system in coastal California, where its course is partly onshore and partly offshore. Understanding the path and amount of San Gregorio–Hosgri fault displacements is important for understanding the geologic history of California and seismic hazard along the California coast. This Special Paper summarizes evidence for 156 km of net San Gregorio–Hosgri fault slip based on an analysis of onshore and offshore geologic mapping supplemented by reappraisal of key geologic features offset by San Gregorio–Hosgri fault movements.

SPE391, 43 p., ISBN 0-8137-2391-4
\$40.00, **member price \$20.00**

In Press

Plates, Plumes, and Paradigms

edited by Gillian R. Foulger, James H. Natland, Dean C. Presnall, and Don L. Anderson

This beautiful compendium of work on hotspot volcanism documents the development, current state-of-play, and future prospects of all branches of the subject. It contains extensive and indispensable reference resources in the form of hotspot, tectonic, volcano and tomographic maps and cross sections of Earth. Some chapters outline the history of the plume hypothesis and other theories for the genesis of hotspots, and several provide tutorials that will be valuable to students and cross-disciplinary scientists. Other chapters present innovative models and theories for individual localities, volcano genesis processes, and related global observations. Many of these include subject reviews, making them doubly valuable to specialists and non-specialists alike. The book is fully interdisciplinary, encompassing geophysics, geochemistry, noble gases, heat, temperature, tectonics, petrology, mantle dynamics, impacts, and syntheses reconciling several branches of earth science. Included are chapters that advocate the plume model and ones that advocate alternative models. The book will enjoy a long lifetime of usefulness and functions as a reference work for students, scholars, and informed lay people. It is equally valuable for supporting advanced undergraduate or post-graduate courses and research scientists working at the forefront of hotspot science. It is an essential addition to the bookshelves of every science library, earth science teacher, and research scientist who aspires to understand the frontiers of this exciting subject. With over 150 color plates, it makes a beautiful addition to the library of anyone fascinated by volcanoes—one of nature's most exciting and extraordinary phenomena.

SPE 388, plus index, ISBN 0-8137-2388-4, in press

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Geological Society Memoir 30: The Neoproterozoic Timanide Orogen of Eastern Baltica

Edited by D. G. Gee and V. Pease

The Neoproterozoic Timanide Orogen of eastern Baltica extends from the high Arctic to the southern Ural Mountains and represents significant crustal growth of the northeastern European continental margin in the late Neoproterozoic. This volume, a co-operation between Western European and Russian scientists within the framework of the European Science Foundation's EUROPROBE programme, provides a comprehensive overview of the orogen and represents a new synthesis of Timanian Orogeny. It includes: the pre-Timanian passive margin deposits of the northern and northeastern flank of the East European Craton; the magmatic, metamorphic and structural evolution of the orogen across the Timan Mountain and Pechora Basin regions to the Ural Mountains; the post-Timanian platform successions, important for interpreting the timing of orogeny and the return to an early Palaeozoic passive margin setting; and the extension of the orogen northwards to Novaya Zemlya. Relationships westwards to the Caledonides of Greenland and Scandinavia and eastwards to the Baikallides of Siberia are also treated.

- ISBN 1-86239-172-6
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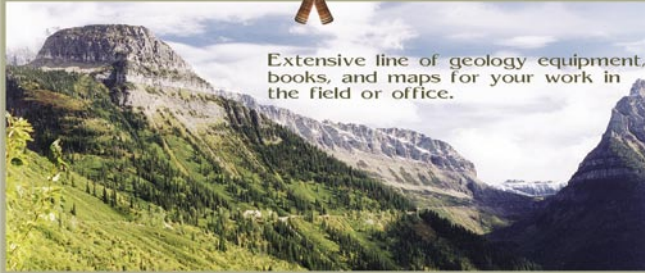
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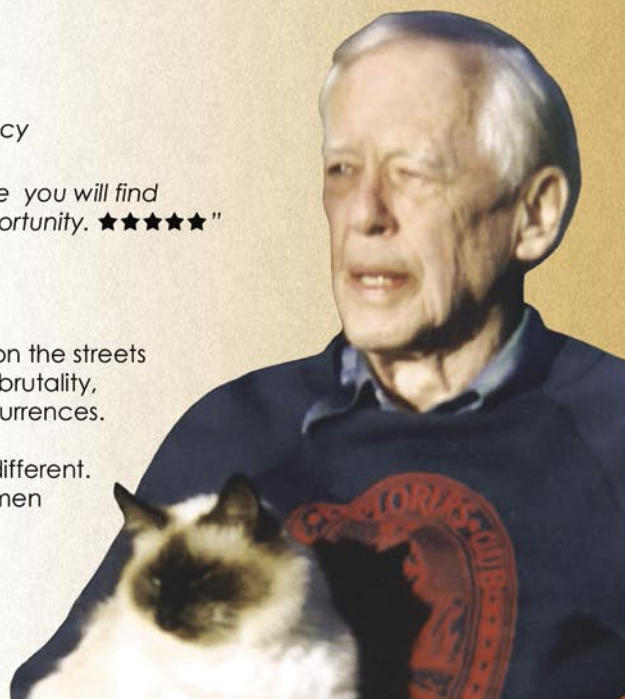
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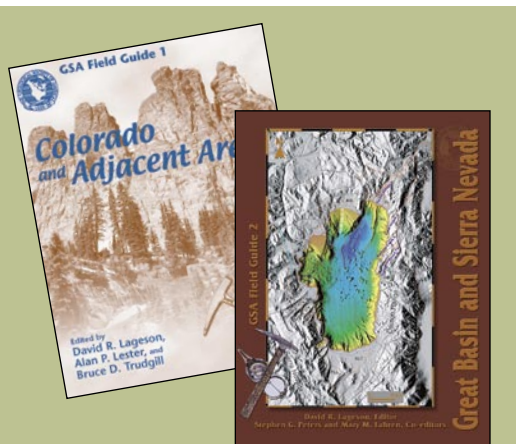
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edited by Eric P. Nelson and Eric A. Erslev, 2004

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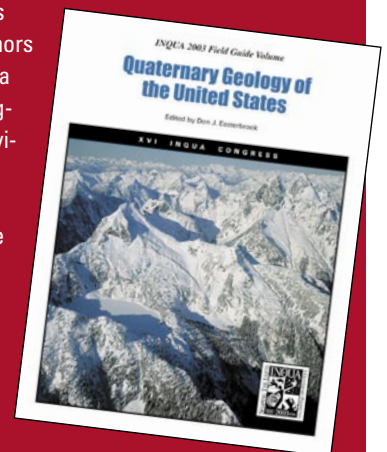
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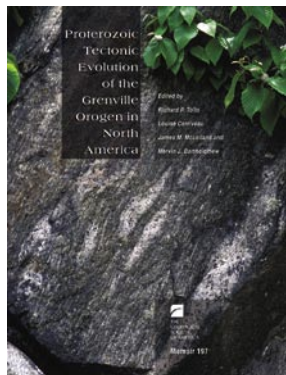
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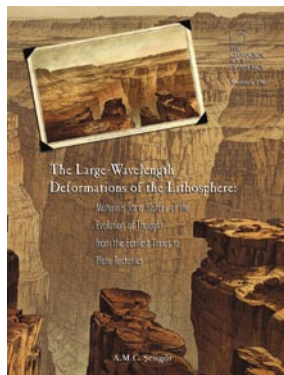


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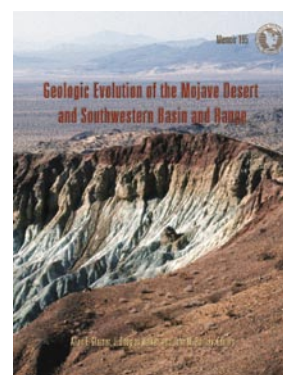


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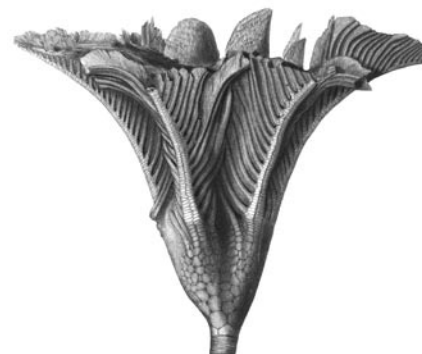
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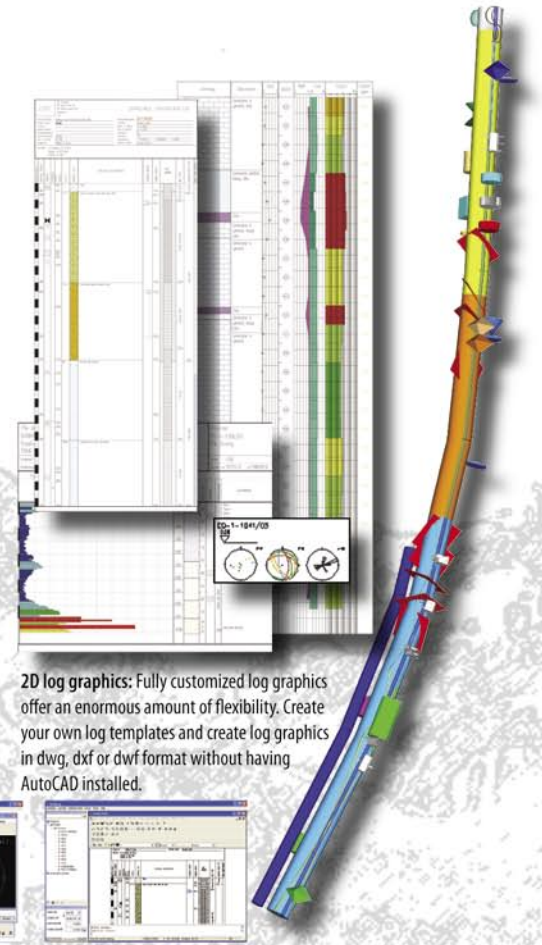
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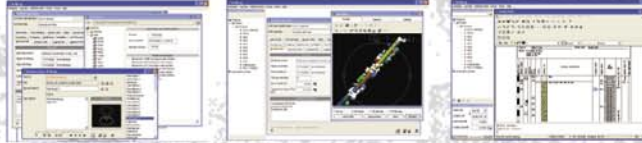
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Easily create cross sections, boring logs, fence diagrams, solid models (ore), stratigraphic and lithologic models, surfaces, contour maps (e.g. elevations and thickness), geotechnical models (e.g. cohesion, compaction, shrinkage, etc.), volumetrics, projected sections, Piper and Stiff diagrams, stereonet, rose diagrams, ternary diagrams and much more!

Item	Desc.	Price
CJ00506	Single User, Academic	\$399
CJ00502	Single User, Commercial	\$999

Other licensing available

Logplot™ v.2005

An easy-to-use boring log plotting program with almost unlimited flexibility in log layout. Plot a single page log for shallow borings, or a multiple page/continuous well log for deep wells.

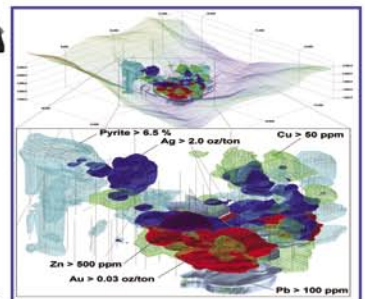
Creating a Logplot Is Simple

1. Select Log Design
2. Enter/Import Your Data
3. Compile & Display Your Graphic Log

Item	Desc.	Price
CJ01680	Single User, Academic	\$199
CJ01679	Single User, Commercial	\$599

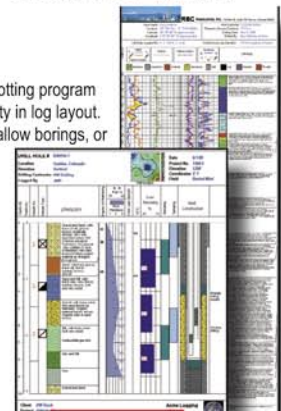
Other licensing available

LogPlot has been widely used in the environmental, petroleum, mining and geotechnical industries since 1983.



RockWorks Training Classes:

June 13-15, 2005 & February 6-8, 2006 - Denver, CO
October 27-28, 2005 - McLean, VA



Geotechnical

Geophysical



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