2013 Presidential Address, p.4

MARCH 2014 | VOL. 24, NO. 3

GSA TODAY

A PUBLICATION OF THE GEOLOGICAL SOCIETY OF AMERICA®

125th anniversary of The Geological Society of America: Looking at the past and into the future of science at GSA

Geosynclinal era 1888 to 1960s

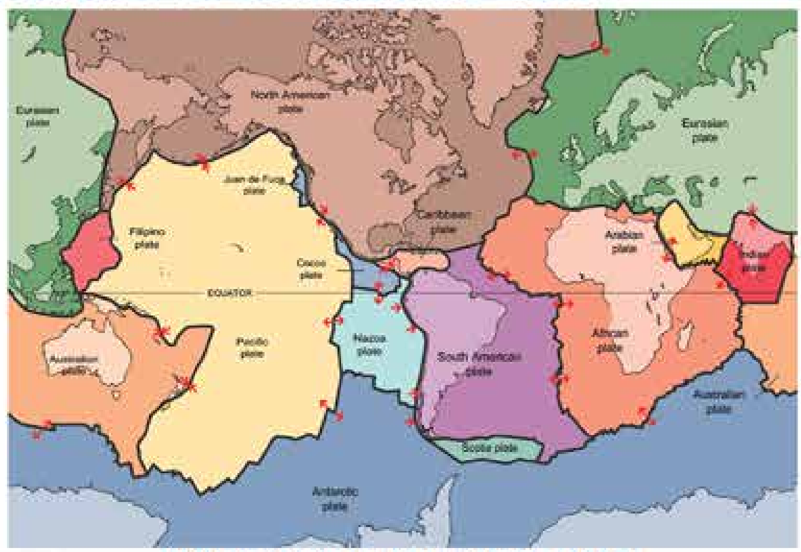
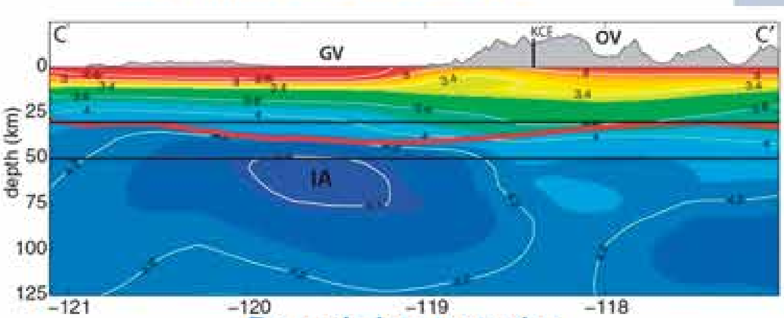
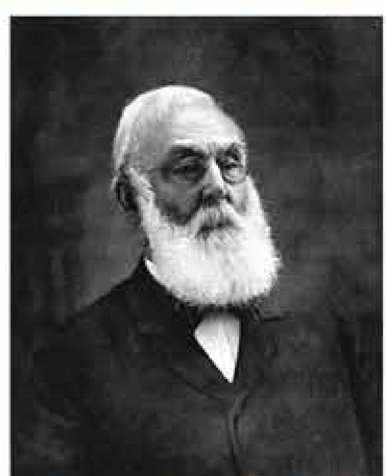


Plate tectonics arrives 1960s–1970s



Beyond plate tectonics



James Hall (1811–1898)
First President and Active Founder of GSA

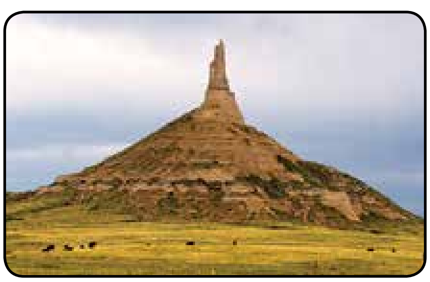
2014 Section Meeting Calendar

www.geosociety.org/Sections/

SOUTH-CENTRAL SECTION
Fayetteville, Arkansas, USA
17–18 March 2014
University of Arkansas
Local Committee chair: Steve Boss

NORTHEASTERN SECTION
Lancaster, Pennsylvania, USA
23–25 March 2014
Lancaster Marriott
Local Committee co-chairs: Noel Potter and Roger Thomas

SOUTHEASTERN SECTION
Blacksburg, Virginia, USA
10–11 April 2014
Skelton Conference Center at Virginia Tech
Local Committee chair: Robert Tracy
Early registration deadline: 10 Mar. 2014



NORTH-CENTRAL SECTION
Lincoln, Nebraska, USA
24–25 April 2014
Cornhusker Marriott
Local Committee chair: Matt Joeckel
Early registration deadline: 24 Mar. 2014

ROCKY MOUNTAIN/ CORDILLERAN SECTIONS
Bozeman, Montana, USA
19–21 May 2014
Montana State University, Strand Union Building
Local Committee chairs: Dave Lageson and Jeff Vervoort
Early registration deadline: 14 Apr. 2014

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Ohiopyle falls at Ohiopyle State Park, Ohiopyle, Pennsylvania; used with permission of Wikimedia Commons.

Blue Ridge Mountains, Shenandoah National Park, Virginia. Photo by Amrinder Arora; used with permission of Wikimedia Commons.

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Grinnell Glacier, Glacier National Park, Montana. Public domain.

GSA TODAY

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Featured Articles

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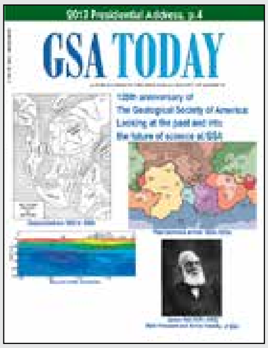

Cover: The history of geoscience at GSA from the geosyncline era (1888 to 1960s; map from Schuchert, 1924) to the plate tectonic era of the 1960s–1970s and beyond (SW to NW shear wave seismic velocity cross section of the Great Valley and Sierra Nevada in California, USA, featuring the Isabella anomaly [from Gilbert, 2012]). GSA's first president, James Hall, was often called the father of geosynclines. See related article, p. 4–11.

ROCK STARS:

GSA News

Errata:

Information regarding the January 2014 *GSA Today* science article, "Massive landslide at Utah copper mine generates wealth of geophysical data," by Kristine L. Pankow and colleagues contained two errors:

1. The cover caption incorrectly states that the date of the landslide was 30 April 2013; it should have said **10** April 2013.
2. The final paragraph on page 4 of the article includes a reference to the 2012 Lituya "Bay" rock avalanche when it should have said Lituya **Mountain** rock avalanche.

GSA Today regrets these errors and thanks the authors for pointing them out.

125th anniversary of The Geological Society of America: Looking at the past and into the future of science at GSA

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ABSTRACT

In the 125th year of The Geological Society of America, it is appropriate to look at the past accomplishments and the future of the Society. With this comes the understanding that it is through curiosity-driven geoscience, whose promotion and communication are hallmarks of GSA, that strides are made in understanding resources, hazards, the global environment, and the factors that influence our survival on planet Earth. Over the years, these advances have come from deductive reasoning based on new and accumulated field and laboratory observations and theoretical modeling, which are continuously taken to new levels by incorporating the latest scientific technology. With this in mind, we examine advances in understanding the origin of mountain belts in the context of the formation and evolution of Earth as our governing concepts have evolved from geosynclinal theory to plate interactions and continental collisions to concepts of continental lithospheric growth and destruction by processes like lower crustal and lithospheric delamination and forearc subduction erosion.

INTRODUCTION

One of the main reasons for the formal founding of The Geological Society of America more than 125 years ago, in 1888, at Cornell University in Ithaca, New York, USA, was to serve as a venue for communication and publications in the geological sciences. A further practical reason was to move the principal annual meeting out of the summer field session as was the practice when meeting with section E of the American Association for the Advancement of Science. Into this framework came the tradition of a presidential address to be delivered at the annual meeting. In looking at the addresses in the past 124 years, there seems to be no limit as to the topics—each address reflects the personality and interest of the president and the time.

Over the years, addresses have centered on the varied facets of geoscience as noted by 1966 GSA President Robert F. Leggett in 1966 (published in 1967), but even in the early years, some were on education, service, and the state of society—with Shaler on education in 1895 (published in 1896); Stevenson on the history of the Society in 1898 (1899); Penrose on "Geology and human welfare" in 1930 (1931); and Collins on "Geology and literature" in 1934 (1935). If we do a survey over the years, we find a large number of addresses on the geology of continents, the structure and tectonics of mountain belts, magmatism and surface processes, with the latest by Joaquin Ruiz on "A renaissance in earth sciences from the core of the Earth to the top of the mountains" in 2010 (not published, but his PowerPoint slides are online at http://www.geosociety.org/gsatoday/archive/21/2/pdf/PresAddressSlides.pdf [last accessed 6 Jan. 2014]). Because this is the 125th anniversary of GSA, I thought I would address the evolution of thought on the continental geological framework as reflected by GSA presidential addresses over the past 125 years, with an eye to the future.

As such I will discuss the transition from geosynclines to plate tectonics to the geologic processes of continents as we see them today, because this in many ways reflects both the history of the geological sciences and the Society. There is in some sense a logical progression—essentially the geosynclinal theory came from observations on the continents, plate tectonics from adding observations on the oceans, and the new directions today from enhanced observations of Earth's interior. A driver of all these ideas has been the advances in technology that have allowed us increasingly to see both smaller and larger segments of Earth, track and isolate its chemical signals, and more precisely measure its movements and temporal evolution.

THE GEOSYNCLINE ERA—STUDIES OF THE CONTINENTS

To start, it is appropriate to consider geosynclines in a historical context as James Hall, the Society's first president, is credited with being the founder of the geosynclinal theory that dominated geologic thinking up until plate tectonics emerged near the GSA's 75th birthday. The geosynclinal theory is also historical, as pointed out by Robert Dott (1978), because it was the first major geological concept made in America. The framework for an Appalachian geosyncline was put forth by Hall in his AAAS presidential address in 1857, but not published until 1882, because Joseph Henry cautioned him to go slowly in advocating such new ideas. Hall (1859, 1882) postulated that localized sedimentary loading caused the crust to subside and form a sediment-filled trough with the future mountain range following the trend of the deepest part of the trough. Down-warping of the trough was proposed to cause material to flow laterally under the rising mountain chain. James Dwight Dana, who became GSA's first vice president, called the crustal down-warp the *geosynclinal region* and argued that collapse of the geosyncline by great folds produced by lateral pressure formed the mountain chain called a *synclinorium* (e.g., Dana, 1873). The compressed crust moved into the region of the future mountain range. Basically, there was a preparatory stage in which sediments accumulated, sourced from an old or border land, and a secondary stage in which these strata were folded and faulted. The Hall-Dana geosynclinal theory was elaborated on in various forms until the advent of plate tectonics in the late 1960s and early 1970s.

"The sites and nature of North American geosynclines" were described by Schuchert in his GSA presidential address in 1922.

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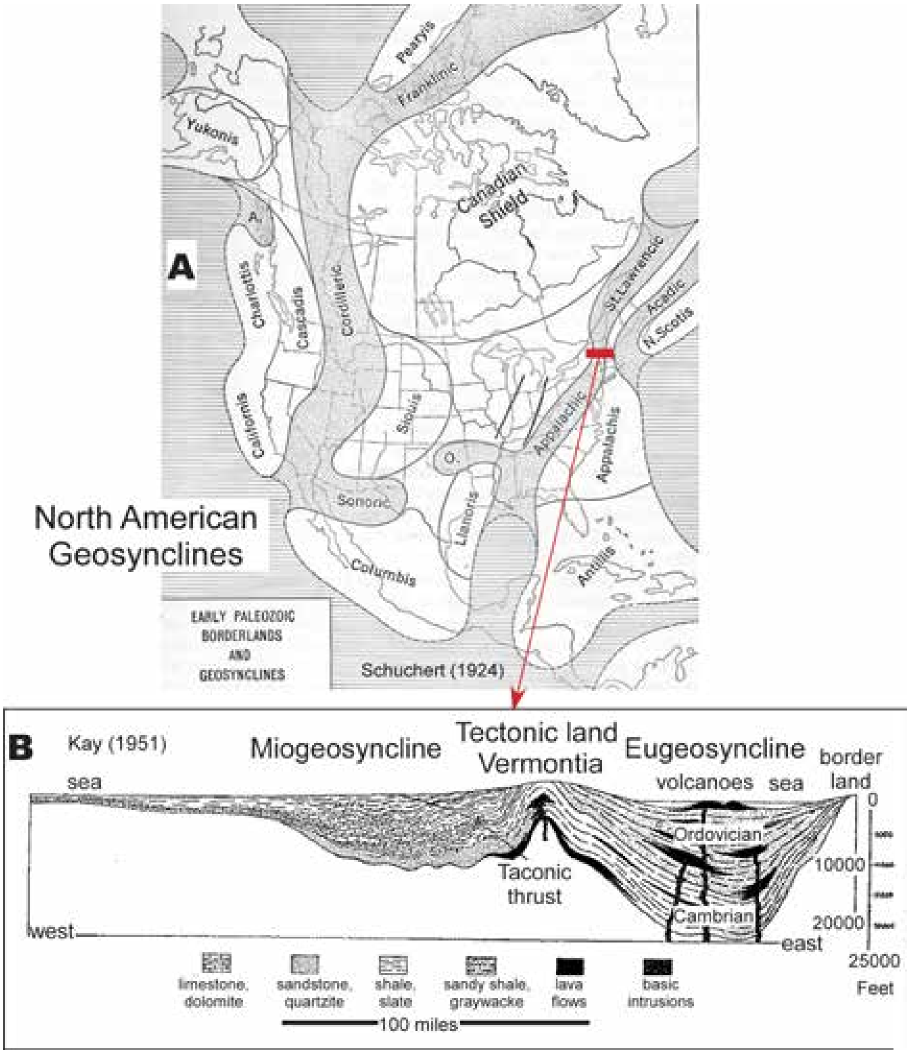

Figure 1. Images of North American Paleozoic geosynclines. (A) Map of North American geosynclines from Schuchert (1924) with stippled areas showing geosynclinal troughs and the white areas as the borderlands (or old lands), which were considered to be the sediment source areas. (B) Cross section across the northern Appalachians after Kay (1951, redrafted by King, 1959) in region of red bar in A showing sediments in the miogeosyncline to the west, volcanic and sedimentary rocks in the eugeosyncline to the east, and the Vermontia tectonic land.

The published version (Schuchert, 1923) has more than 125 citations in Google Scholar, which is a large number for a publication of that vintage. The map in Figure 1A illustrates the concept of the old lands or borderlands that were the sediment sources on the borders of the geosynclines. There was no information on what lay below the oceans. Another important component of the geosynclinal theory was that the continents were fixed. The borderlands were given names like Siouis and Llanoris. Part of Llanoris and some of the southeast borderlands are now considered to have been rifted away to form the Cuyania terrane in modern Argentina, as discussed by William Thomas in his 2005 presidential address (Thomas, 2006).

A comprehensive study on North American geosynclines by 1970 Penrose medalist Marshall Kay was published as GSA Memoir 48 in 1951 and subsequently reprinted three times and translated into four languages. It has more than 600 citations on Google Scholar. Kay incorporated the miogeosyncline and eugeosyncline names of Stille (1941) and illustrated them in a cross section (see Fig. 1B) across the northern Appalachians in the region where the Hall-Dana geosyncline concept had been developed. The miogeosyncline includes the down-warped sediments in a trough to the west, and the deeper eugeosyncline contains immature sandstones, lava flows, and basic igneous intrusives (Steinmann's trinity: serpentine, pillow lavas, and chert) to the east. They are shown separated by the mountains of the Vermontia tectonic land. Kay emphasizes that not all American geosynclines fit this simple model and the growing complexities are indicated by his list of geosynclinal types (Zeugo, Exo, Auto, Epieu, Taphro, and Paralia). In Memoir 48, Kay (1951) provided a North American map for the Ordovician in which he showed clouds blowing in the wind on the borderlands to indicate poetically the uncertainties in those regions.

The importance of the geosynclinal theory until the 1960s is shown in the 1944 GSA presidential address of Adolph Knopf titled "The geosynclinal theory." In the 1948 publication of his address, he states, "From … examination it appears that the geosynclinal doctrine is likely to prove to be a great unifying principle, possibly one of the greatest in geologic science" (p. 667). The theory was well-rooted in textbooks all around the world into the 1960s. An abbreviated quote from the historical geology text of Clark and Stearn (1960) reads, "The geosynclinal theory is one of the great unifying principles in geology … of fundamental importance to … all branches of geological science. The geosynclinal origin of major mountain systems is an established principle in geology" (p. 43). It is clear that caution is needed in making such proclamations.

The geosynclinal theory was commonly mentioned in GSA presidential addresses through the late 1940s, like those of Gilluly in 1948 (published in 1949), Longwell in 1949 (1950), Woodring in 1953 (1954), Bucher in 1955 (1956), Billings in 1959 (1960), Hedberg in 1960 (1961), and Krauskopf in 1967 (1968). The last president to mention geosynclines was Rodgers in 1970 (1971), who was on the cusp, as he also talked about plate tectonics theory.

One of the regions where the geosyncline concept of North America and Europe did not work well was in South America, where the central Andes seemed quite different. Albert Heim, for one, noted that unlike European geosynclines, marine and continental flysch were essentially absent, andesitic magmatism was pervasive, open and low-amplitude folds prevailed, and high *P-T* metamorphic assemblages were largely absent (MacLaren and Duff, 1993). Aubouin and Borrello

(1966) suggested calling the central Andes a liminal chain to emphasize the difference.

Through the years, the geosynclinal model grew in complexity and away from unifying principles. A real problem was that there seemed to be a wide variety of geosynclinal styles and stages with no real general model and no clear testable driving mechanism that caused the mountains to form. Another problem was what happened to the borderlands on the edges of continents that magically disappeared into the oceans. The geosynclinal theory required older rocks in the borderlands to serve as source regions for the geosynclinal belts, yet both younger and older rocks were being found on continental margins. At the same time, there were strong geologic arguments that the continents had moved. Among early proponents were Alfred Wegener in Germany, Juan Keidel in Argentina, and Alexander Du Toit in South Africa. By 1960, the fit of the continents was widely discussed, and some ancient mountain belts separated by oceans seemed to have been connected. The discussion was particularly evident in the southern continents, where the Paleozoic to Mesozoic SAMFRAU (South America to Africa to Australia) geosyncline was postulated, with the recognition that the Paleozoic to Mesozoic paleontological links had disappeared by the Cenozoic. Other evidence for connections and breakups came from Paleozoic glacial sediments and paleomagnetic data. Opposition to continental drift came largely from a lack of a viable mechanism, and, perhaps, a northern hemisphere–centric view of much of the research community. The chinks were forming in the armor of the geosynclinal theory.

THE PLATE TECTONICS ERA—INCORPORATING THE OCEANS

By the 1960s, the ocean basins were being explored with an increasing number of seismic and magnetic techniques, and the ocean floor was being cored and dated. Among early pioneers were Penrose medalists Harry Hess (1966) and Maurice Ewing (1974) and Day medalist Fred Vine (1968) and collaborator Drum Matthews. Contrary to the geosynclinal hypothesis, the ocean floor was found to be young and basaltic. The new data and evolving plate tectonic theory showed that the ocean floor was continuously forming at ocean ridges and subducting beneath the continental margins. These observations allowed the continents to move, removing the objection to continental drift.

The theory of plate tectonics, which joined continental drift with seafloor spreading, led to the plate tectonic revolution of the 1960s and 1970s, with all of the problems of geosynclines seeming to disappear—as did geosynclinal theory. Jack Bird and 1992 Penrose medalist John Dewey put the classic northern Appalachian geosyncline into the plate tectonic framework (Bird and Dewey, 1970). Among many key players were GSA Penrose medalists J.T. Wilson in 1968, Robert Dietz in 1988, and A.E. Ringwood in 1974, and 1987 GSA president Jack Oliver in 1998.

The plate tectonics revolution can be seen in the GSA presidential addresses, with the word geosyncline disappearing after John Rodgers in 1970, who also used plate tectonics in addressing "The Taconic orogeny" (1971). Since that time, almost all addresses have mentioned plate tectonics.

The concepts of plate tectonics, including seafloor spreading, subduction and volcanic arcs, continental collisions, plumes, and hotspots, are taught universally in geoscience curriculums today and are commonly used in documentaries and the public news media. Many have said in parallel with statements on the geosynclinal theory, "Plate tectonic theory is a great unifying principle of fundamental importance to all branches of the geological science." A question to ponder is what will be said 50 years from now.

BEYOND PLATE TECTONICS—WHOLE EARTH VIEWS

As with the era of geosynclines, the plate tectonic era began with a simple view of how to explain mountain-building processes and continents in a unified framework. Out of plate tectonics has grown a whole new set of questions whose origins are closely connected with an ever-expanding technology that has allowed us to constrain timing and look deep into the Earth. Technological advances have led to an explosion of age constraints, particularly connected with precise U/Pb dating of zircons ("a miracle mineral"), Ar/Ar technology, and a host of other methods leading to temporal precision not before possible. Notable advances in geochemistry and geophysics have expanded our ability to track material at the surface and deep into the interior with new imaging techniques providing views of Earth's interior that were unimaginable 50 years ago. Advances in computer technology allow manipulation of huge databases and production of endless strings of numerical models.

I will highlight a few of the frontier areas in looking at the Earth and into its interior where our understanding of tectonic processes is ongoing and hotly debated. These frontiers include recycling of continental crust through sediment subduction and forearc subduction erosion at convergent margins, foundering of mantle lithosphere and dense crust under arcs and continents (delamination), implication of ultra-high pressure (UHP) metamorphic signatures in upper crustal rocks for the subduction of continental crust, and the ultimate fate of subducted slabs and continental crust and lithosphere.

The first of these areas is the question of sediment subduction and forearc subduction erosion, which remove continental crust at convergent margins. In overview papers, von Huene and Scholl (1991), Clift and Vannucchi (2004), and Scholl and von Huene (2007) argue that most active subduction zones (>80%) are erosional, with pieces of the overriding plate plucked from the hanging wall and subducted to unknown depths. The general model for subduction erosion after von Huene et al. (2004) is shown in Figure 2A. The quantities of sediment subducted and forearc removed, along with their ultimate fate, are currently hotly debated topics. Amounts of recycled crust are commonly expressed in Armstrong Units (after Dick Armstrong) with 1 AU being 1 km^3/yr. Proposed global removal amounts by subduction erosion have varied from 1.1 to 1.7 AU. Scholl and von Huene (2007) pointed out that at these rates, the volume of continental crust today would be recycled by subduction erosion in less than 2.5 billion years. Stern (2011) and others argue that geochemical analyses show that arc magmatism brings back no more than 10% of the subducted crust. Some overall estimates suggest that at modern rates the crust is actually shrinking, although actual long-term loss depends on many factors. Forearc subduction erosion along with continental rifting aids in solving the old borderlands problems of the geosyncline era.

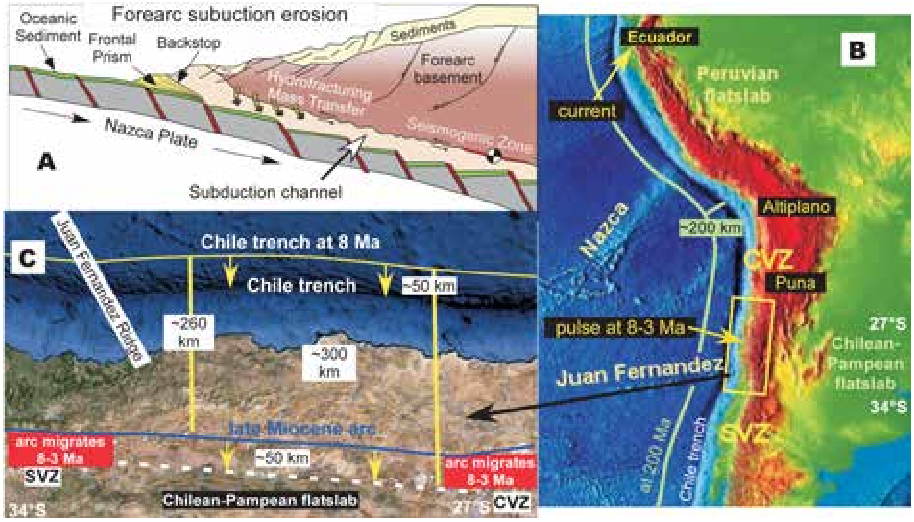

Figure 2. Images for forearc subduction erosion. (A) Figure adapted from von Huene et al. (2004) and Goss and Kay (2006) showing the general model for forearc subduction–eroded material transported in the subduction channel between the upper and lower plate. (B) Relief map of the Andes showing the Chile trench, the subducting Nazca and Juan Fernandez aseismic ridges on the Pacific plate, and the high central Andean Puna–Altiplano plateau and surrounding flat-slab regions. The green line shows the approximate position of the Chile trench at ca. 200 Ma given that the trench has migrated eastward in response to forearc subduction erosion as tracked by the eastward displacement of the magmatic arc (e.g., Scholl and von Huene, 2007). The yellow arrows point to regions of forearc subduction erosion pulses at 8–3 Ma on the Chilean margin and today on the Ecuadorian margin. (C) Google Earth image illustrating the proposed ~40–50 km displacement of the Chilean trench between 27°S and 34°S to compensate for the eastward displacement of the magmatic arc (Kay et al., 2005; Goss et al. 2013; see text).

The South American margin (see Fig. 2B) is commonly singled out in discussions of forearc subduction erosion because the concept arose there to explain the eastward stepping of the late Jurassic to recent arc, which cannot be explained by strike-slip tectonics. The conjecture is that ~200 km of the margin has been lost in the last 200 million years (Rutland, 1971). More recently, much of the loss has been suggested to be episodic. Some suggested that short-term local rates are 96–128 km^3/m.y./km for the past 10 m.y. (Laursen et al., 2002) near the Juan Fernandez ridge (Fig. 2B), with the highest rate yet suggested of ~440 km^3/my/km at the Chile ridge-trench triple junction further south near 46°S latitude (Bourgois et al., 1996).

Looking at a specific Andean example (Figs. 2B and 2C), 40–50 km of the Chilean forearc near 34°S and 27°S on the margins of the amagmatic Pampean-Chilean flat-slab appears to have been removed by subduction erosion between 8 and 3 Ma, with much of the evidence coming from a 40–50-km eastward displacement of the frontal arc and the distinctive "adakitic" geochemical signatures of the contemporaneous magmas (Kay et al., 2005; Goss et al., 2013). Given a constant ~300-km arc-trench gap and subduction erosion across the intervening flat slab (Fig. 2C), a major pulse of subduction erosion at a rate of >190 km^3/my/km affected ~700 km of the margin from 8 to 3 Ma, during the time of the most rapid shallowing of the flat slab (Kay and Mpodozis, 2002). Several intriguing observations are related. One is the suggestion of Allmendinger et al. (1990) that a potential crustal mass balance problem with the 137 km of crustal shortening that they calculated in a transect at 30°S could be solved by forearc subduction erosion. Another is that the low seismic Vp/Vs ratios in the mantle wedge above the flat-slab attributed to orthopyroxene related to sediment subduction by Wagner et al. (2008) is actually related to forearc crust entering the mantle wedge as the slab shallowed.

A second area of heated discussion is delamination or gravity-driven foundering of dense continental lithosphere into the underlying mantle. The original hypothesis was by Peter Bird (1979) to explain thinning of the mantle lithosphere in the western U.S. associated with Laramide shallow subduction. Lithospheric removal can also explain thinned lithosphere, uplift, volcanism, and changes in deformation patterns as argued in Tibet in papers by England, Houseman, Molnar, and others (e.g., England and Houseman, 1989). Linking the delamination of mantle lithosphere with that of cold, dense mafic lower crust helped to provide a viable sinker as well as an explanation as to why the bulk composition of the crust is andesitic (Kay and Kay, 1993). These suggestions were initially received with skepticism, but recognition of a thinner mantle lithosphere than expected from contractional shortening in orogenic regions, unexpected high elevation, and distinctive magmatic patterns and chemistry has led to a proliferation of suggested and debated delamination sites.

In North America, continental lithospheric removal has been most discussed under the Sierra Nevada and Great Basin and the Colorado Plateau, with evidence coming from xenoliths, field and modeling studies, and seismic studies. The problem of an andesitic crust had long been recognized in the Sierra Nevada, and the studies of Zandt, Saleeby, Ducea, and coworkers (e.g., Zandt et al., 2004) have suggested the cause is the delamination of lower crust. Recent seismic images in Gilbert et al. (2012) and Saleeby et al. (2012) show what is interpreted to be a foundered, but likely still attached, lithospheric block ("drip") extending to depths of >100 km under the Great Valley in California. Another debated example put forth by Levander et al. (2011) is an interpreted lithospheric drip reaching a depth of 250 km on the southwestern edge of the Colorado plateau. Various western U.S. seismic anomalies seen with EarthScope transportable seismic array data are being interpreted by Humphreys and other workers (e.g., Schmandt and Humphreys, 2011) as residual pieces of the subducted Farallon plate.

It is in the central Andean Puna–Altiplano plateau (Fig. 3A), which stands at an elevation of >3700 m, that some of the most intense discussion on lithospheric delamination has taken place and where some of the most convincing evidence exists. The original Kay et al. (1994) hypothesis for delamination of crustal and mantle lithosphere in a transect near 26°S, shown in the cartoon in Figure 3B, was based on the criteria used for lithospheric delamination in Tibet, with additional constraints from the geochemistry of the lavas. Seismic evidence was lacking at the time, but this has changed as studies have proliferated throughout the central Andes.

The now popular lithospheric-scale cartoon in Beck and Zandt (2002) based on seismic studies in the southern

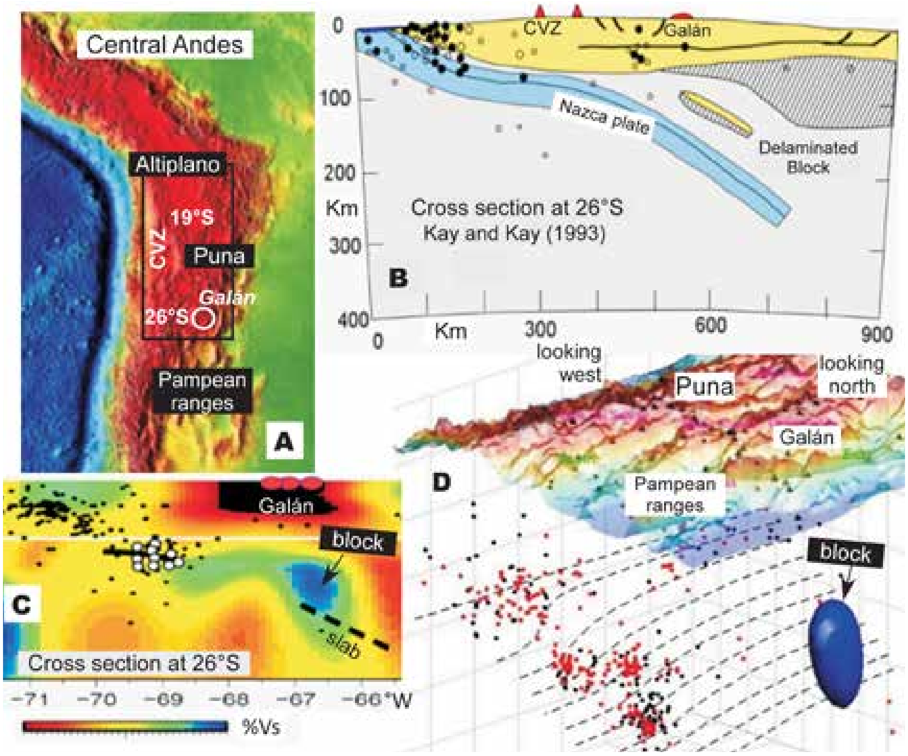

Figure 3. Images for delamination of crust and mantle lithosphere. (A) Relief map showing the central Andean Puna–Altiplano plateau and central volcanic zone (CVZ) arc with the black box bounding areas where continental and crustal lithospheric delamination has been imaged. (B) Cartoon cross section at 26°S from Kay and Kay (1993) showing delaminated crustal (yellow) and lithospheric mantle (striped) under the backarc beneath the 6–2 Ma Cerro Galán ignimbrite caldera. (C) Surface wave tomographic image (in %Vs) based on Calixto et al. (2013) in an east-west transect at 26°S showing low velocity region (blue) interpreted as delaminated block above slab (dashed line). (D) Image modified from Calixto et al. (2013) showing delaminated block above the subducting slab under Cerro Galán. Dots are earthquake hypocenters; open and red circles are the best located.

Altiplano near 19°S shows a gap in the continental lithosphere attributed to removal under a crustal region thought to contain melt. This gap is attributed to delamination, although there is no evidence as to what happened to the missing piece. Subsequent seismic images further south near 23–24°S shown by Schurr et al. (2006) reveal a low-velocity region in the mantle above the subducting slab, which they interpret as a delaminated block. An overlying low-velocity region is attributed to decompression melting above the delaminated block. With these images, the delamination model gained credibility in the Andes, with the size and frequency of the blocks or drips still being hotly debated topics today.

Some of the most recent evidence for delamination in the Puna plateau comes from the Vs tomographic image from Calixto et al. (2013) at latitude 26°S, which is at the same latitude and shown at the same scale as the Kay et al. (1994) cross section (Fig. 3B). The high-velocity area in blue above the inferred slab is interpreted to be the delaminated block, with the overlying low-velocity anomaly in red attributed to a zone of partial melt below the giant Cerro Galan ignimbrite caldera. A 3-D perspective of the delaminated block is shown in Figure 3D.

A third emerging research area is associated with exhumation of continental crust that has been subjected to ultra-high pressure (UHP) metamorphism. A key in recognizing these terranes is the presence of minerals like coesite and diamond. In a review, Hacker et al. (2013) describe how observed UHP terranes range from large or small, can be exhumed at plate tectonic or slower rates, can be variably deformed, may or may not be associated with melting, and can have different thermal histories. They investigate the various proposed origins with numerical modeling and conclude that UHP terranes form by a wide variety of mechanisms, some of which may not have yet been imagined. Most models associate UHP metamorphism with subduction of continental margins because the *P-T* conditions fit, and subduction zones provide the pathway. The most common model following Chemenda et al. (1995) (Fig. 4A) is for a thin crustal sheet to be detached from a block of subducted continental lithosphere at ~100 km depth and then be rapidly exhumed as convergence proceeds. However, this model cannot explain the large eastern China Dabie–Sulu terrane or the Western Gneiss Region terrane in Norway, which show evidence for slow subduction and exhumation histories of tens of millions years without strong deformation. A proposed "eduction" model following Anderson et al. (1991) (Fig. 4B) calls for a reversal of relative motion of the down-going plate in association with slab breakoff. A third type of UHP is seen in Papua New Guinea, where metamorphism appears to postdate subduction by >20 million years. A working model following Little et al. (2011) (Fig. 4C) shows this UHP terrane being exhumed as a diapir.

Another question is assessing the flux of silicic continental material that enters the mantle and returns to the base of the continental crust. In one scenario, Hacker et al. (2011) argue that silicic rocks transform into felsic gneisses that form melts and then rise buoyantly to "relaminate" to the base of the crust. They envision relamination of subducted sediment, subducted intra-oceanic arc crust, forearc subducted crust, and subducted continental crust. Quantitative tests await crustal mass balance for these models.

A final question is the quantity of continental crust and lithosphere that is subducted or delaminated into the convecting mantle, and the fate of this material. Some have argued for dispersal of foundered continental lithosphere in the upper mantle after breakup of supercontinents. Evidence as to whether crust also enters the deeper mantle is centered on the chemistry of ocean-island basalt (OIB). Many geochemists have argued that the chemical variability of OIB can be adequately explained by

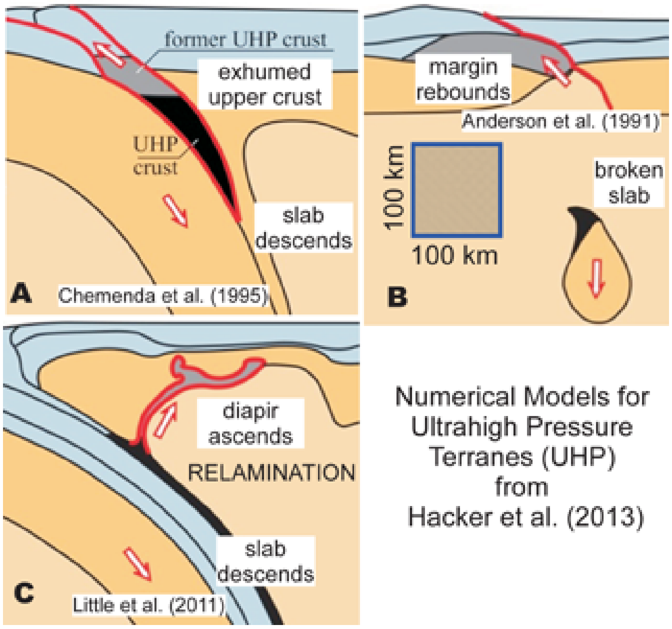

Figure 4. Images of numerical models to explain ultra-high pressure metamorphism in continental crust (UHP terranes) from a review by Hacker et al. (2013). Scale for all is in patterned box in B. (A) Subducted piece of the upper continental crust at a collisional margin detached at ~100–150 km depth and exhumed by buoyancy before slab breakoff. (B) Exhumation of a large block on a normal fault as motion reverses after slab breakoff. (C) UHP rocks rise through the mantle as a diapir, resulting in relamination. Modified from Anderson et al., 1991; Chemenda et al., 1995; Hacker et al., 2013; and Little et al., 2011.

subducted ocean crust and sediments. However, some like Willbold and Stracke (2010) now argue that lower continental crust removed by forearc subduction erosion and/or delamination is required, because recycling of marine sediments alone cannot completely account for features like positive Eu anomalies and lower crustal-like isotopic signatures. The only way to obtain such signatures from subducted sediments is the unlikely erosion of large, unobserved tracts of exhumed lower crust, whereas subduction erosion and delamination provide a way for lower crust to enter the mantle. Willbold and Stracke point out that erosive margins like the Andes seem to require removal of crust, and that lower crust is sufficiently dense and dry to sink with the slab into the deep mantle without melting. If plate tectonics has operated since the late Archean, sufficient recycled continental material can enter the deep mantle to explain the range of signatures in OIBs. They consider two end-member possibilities to explain the OIB chemistry. In the first, continental crust is transported deep into the mantle by subduction and brought up in plume magmas generated in a locally mixed mantle. In the second, the plume is derived from a stirred marble cake mantle containing delaminated crust and subducted slabs.

Herein, we have only looked at a few of the present frontiers. Among many other questions are the following: Do plumes really exist? What is the role of supercontinent cycles? How did the early Earth evolve? How did the core form and how do magnetic reversals work? When did plate tectonics begin? What is the history of crustal growth? Advances in all of these areas will come from deductive reasoning based on new and accumulated field and laboratory observations and theoretical modeling—all continuously taken to new levels by the latest technology.

FINAL REMARKS

With this short overview of studies of the American Cordilleras and the continents and oceans, we see an evolution of geoscience theory that will continue into the future as new ideas enhance the understanding of our planet and have implications for hazards, resources, sustainability, climate change, and other unknown challenges.

Compared to the GSA founders in 1888, we have a more global view today and face an increasing challenge to follow a rapidly expanding scientific database and scholarly literature. What tomorrow will bring is for our successors at future GSA meetings to tell in the scientific communication style of the time.

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NOTICE of Spring 2014 GSA Council Meeting

GSA Council will meet next on Saturday, 26 April, 9 a.m.–4:30 p.m., and Sunday, 27 April, 7–10:30 a.m. The GSA corporate meeting will be Saturday, 26 April, 4:30–5 p.m. All meetings will be held at GSA Headquarters, 3300 Penrose Place, Boulder, Colorado, USA.

Meetings of the GSA Council are open to Fellows, members, and associates of the Society, who may attend as observers, except during executive sessions. Only councilors and officers may speak to agenda items, except by invitation of the chair.

THE GEOLOGICAL SOCIETY OF AMERICA®

GSA ELECTIONS

GSA's success depends on you—its members—and the work of the officers serving on GSA's Executive Committee and Council.

In early March, you will receive a postcard with instructions for accessing your electronic ballot via our secure website, and biographical information on the nominees will be online for you to review at that time. Paper versions of both the ballot and candidate information will also be available.

Please help continue to shape GSA's future by voting on the nominees listed here.

2014 OFFICER AND COUNCIL NOMINEES

PRESIDENT
We congratulate our incoming President (July 2014–June 2015), who was elected by GSA membership in 2013: **Harry (Hap) Y. McSween Jr.** of the University of Tennessee–Knoxville.

VICE PRESIDENT/PRESIDENT ELECT
(July 2014–June 2016)
Jonathan G. Price
Jonathan G. Price, LLC
Reno, Nevada, USA

TREASURER
(July 2014–June 2015)
Bruce R. Clark
The Leighton Group Inc.
Irvine, California, USA

COUNCILOR POSITION 1
(July 2014–June 2018)
Aaron Cavosie
University of Puerto Rico–Mayagüez
Mayagüez, Puerto Rico

Anke M. Friedrich
Universität München
Munich, Germany

COUNCILOR POSITION 2
(July 2014–June 2018)
Timothy Bralower
Pennsylvania State University
State College, Pennsylvania, USA

Shuhai Xiao
Virginia Polytechnic Inst. and State University
Blacksburg, Virginia, USA

COUNCILOR POSITION 3
(Section Representative to Council)
(July 2014–June 2018)
Stephen G. Pollock
University of Southern Maine
Gorham, Maine, USA

Alan E. Kehew
Western Michigan University
Portage, Michigan, USA

Elections begin 7 March 2014. Ballots must be submitted electronically or postmarked by 6 April 2014. www.geosociety.org/aboutus/officers.htm

CALL FOR AWARD NOMINATIONS

JOHN C. FRYE ENVIRONMENTAL GEOLOGY AWARD

Nominations due 31 March

What's the best paper on environmental geology you've read lately?

This US$1,000 cash award recognizes the best paper on environmental geology published by GSA or by a state geological survey within the past three years. To nominate a report, please submit a letter describing its importance, with up to three letters from users of the publication, along with three copies of the publication, to Program Officer, Grants, Awards & Recognition, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA, awards@geosociety.org. Funds for this award are managed by the GSA Foundation.

QUATERNARY GEOLOGY AND GEOMORPHOLOGY DIVISION FAROUK EL-BAZ AWARD FOR DESERT RESEARCH

Nominations due 2 April

This award recognizes excellence in desert geomorphology research worldwide. Any scientist may be nominated for this award, and applicants need not be geologists, U.S. citizens, or members of GSA. To nominate, send a statement of the significance of the nominee's research, the nominee's curriculum vitae, letters of support, and copies of no more than five of the nominee's most significant publications related to desert research to David P. Dethier, ddethier@willilams.edu. Monies for this award, which are derived from the annual interest income of the Farouk El-Baz Fund, are managed by the GSA Foundation.

Students: CALL FOR APPLICATIONS

ANTOINETTE LIERMAN MEDLIN SCHOLARSHIP IN COAL GEOLOGY

Applications due 15 March

GSA's Coal Geology Division announces the availability of the Antoinette Lierman Medlin Scholarship, which provides monetary support and recognition to deserving students in coal science. Monies from the scholarship are used toward successful completion of students' research projects. Each year, one award is presented for the completion of laboratory/analytical research (US$2000) and a second award is presented for the completion of fieldwork (US$1500).

Full-time graduate students are strongly encouraged to submit applications for these scholarships. Applications should consist of a five-page summary of their research and an explanation of how the stipend would enhance that research. A one-page letter from the student's immediate supervisor supporting the need for funding is also required. The awardee will be notified in early April. Applications should be sent to the Medlin Scholarship Chair, Jen O'Keefe, at j.okeefe@moreheadstate.edu. For more information, please go to www.uky.edu/KGS/coal/GSA/awards.htm.

HISTORY AND PHILOSOPHY OF GEOLOGY STUDENT AWARD

Applications due 1 May

GSA's History and Philosophy of Geology Division is offering a US$1000 award for proposals for a student paper to be presented at an upcoming GSA Annual Meeting. The topic of the proposed paper may be (1) the history and philosophy of geology; or (2) a literature review of ideas for a technical work. If you have questions about the award, please contact David W. Goldsmith, dgoldsmith@westminstercollege.edu. For more information, please go to www.gsahist.org/hapg_award/student_award.htm.

Philmont Scout Ranch Volunteer Geologist Program

Cimarron, New Mexico, USA
Sponsored by the Rocky Mountain Association of Geologists

VOLUNTEER TO TEACH AND DEMONSTRATE AREA GEOLOGY IN BACK-COUNTRY NEW MEXICO THIS SUMMER!

Philmont Scout Ranch is one of three national high-adventure bases owned and operated by the Boy Scouts of America. Located in the southern Sangre de Cristo Mountains of northern New Mexico, Philmont is a 137,000-acre ranch dedicated to outdoor activities. The twelve-day backpacking experience serves more than 27,000 high-school-age boys and girls from all over the USA as well as several foreign countries. Learn more about the geology of the area at **http://pubs.usgs.gov/pp/pp_505/html/pdf.html.**

Fifty-four volunteer positions are open this year, to be filled on a first-come, first-served basis. Volunteers will receive a sign-up packet with scout applications (you have to be a scout, at least for the summer!), medical forms, and brochures in May 2014. Students who would like to volunteer must show proof of enrollment in a graduate-level program. The 2014 season begins on Saturday, 14 June; the last week of the program begins on Saturday, 9 August.

For more information and to sign up, contact Ed Warner, 62 South Ash Street, Denver, CO 80246, USA, +1-303-331-7737, ewarn@ix.netcom.com. Alternate contact: Bob Horning, P.O. Box 460, Tesuque, NM 87574, USA, +1-505-820-9290, rrhorning@gmail.com.

FIELD OPPORTUNITIES

GSA/ExxonMobil Field Awards

Deadline to apply: 18 April

The importance of field schools to practicing geologists is unquestionable; yet, the opportunities to experience field geology are dwindling. The Geological Society of America (GSA), in cooperation with ExxonMobil, is currently offering three programs to support and encourage field geology. This non-profit/industry collaboration has proven very successful, and each year more than 600 geology students and professors apply for these awards.

THE GSA/EXXONMOBIL BIGHORN BASIN FIELD AWARD

This is a one-week field seminar that offers 20 undergraduate and graduate students and five faculty members a chance to receive a high-quality educational experience in the spectacular Bighorn Basin of north central Wyoming, USA. The course is free to accepted participants, and all transportation, meals, and living expenses are covered. The seminar focuses on multidisciplinary integrated basin analysis and enables awardees to study exposures of individual hydrocarbon system play elements, such as source, seal, reservoir and structure, within a prolific hydrocarbon basin. For more than a century, the Bighorn Basin has been studied by academic, industry, and government geoscientists, who have focused on the exceptional outcrop exposures, as well as subsurface borehole and seismic data. Our current understanding of the basin derives from both industry and academic perspectives. This seminar is team taught by four ExxonMobil professionals, who represent more than 100 years of combined research in integrated basin analysis, with specific skills in tectonics, geochemistry, structure, sequence stratigraphy, sedimentology, paleontology, hydrocarbon systems analysis, and integrated play analysis. GSA will select the awardees and handle all logistics.

What people are saying:

"It was one of the most invaluable experiences of my lifetime."

*"That was a fantastic course.
I learned so much! It was an honor to go."*

THE GSA/EXXONMOBIL FIELD CAMP SCHOLAR AWARD

This award provides undergraduate students US$2,000 each to attend the field camp of their choice, based on diversity, economic/financial need, and merit. Funds for this award have been provided by ExxonMobil; selections of awardees are completed by GSA.

What people are saying:

"The experience was unforgettable. The scholarship afforded me this great opportunity to strengthen my education, which I would otherwise have not been able to finance. I am truly grateful."

"For me, this was a once in a lifetime experience, and having spent an entire summer in this immersive program has laid a solid foundation as I move forward in my career as a glaciologist. Thank you for providing me the financial support in this vital step of my academic career."

THE GSA/EXXONMOBIL FIELD CAMP EXCELLENCE AWARD

This award provides one geologic field camp leader US$10,000 to assist with his or her summer field camp based on safety awareness, diversity, and technical excellence.

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https://rock.geosociety.org/ExxonMobilAward/index.asp

Final Announcement

JOINT SECTION MEETING

66th Annual Meeting of the Rocky Mountain Section, GSA
110th Annual Meeting of the Cordilleran Section, GSA
19–21 May 2014
Bozeman, Montana, USA

www.geosociety.org/Sections/rm/2014mtg/

Grinnell Glacier, Glacier National Park, Montana, USA. Image by Mountain Walrus, Wikimedia Commons.

LOCATION

Bozeman is a beautiful town located in the Gallatin Valley of southwest Montana (Montana's fly fishing epicenter), just north of Yellowstone National Park. It is surrounded by world-class geology, and an outstanding group of pre- and post-meeting field trips will highlight local and regional aspects of the geology of the Northern Rocky Mountains.

REGISTRATION

Early registration deadline: 14 April
Cancellation deadline: 21 April
REGISTRATION FEES (all fees are in U.S. dollars)

	EARLY		STANDARD	
	Full Mtg	One Day	Full Mtg	One Day
Professional member	$190	$90	$230	$100
Professional nonmember	$210	$160	$240	$200
Professional 70+	$70	$55	$70	$60
Student member	$45	$30	$55	$40
Student nonmember	$60	$45	$80	$65
K–12 Teacher	$50	$25	$60	$30
Guest/Spouse	$45	n/a	$55	n/a
Field trip/workshop only	$30	n/a	$30	n/a

ACCOMMODATIONS

Hotel reservation deadline: 20 April

A block of rooms has been reserved at the Hilton Garden Inn Bozeman, 2023 Commerce Way, Bozeman, MT 59715, USA; +1-406-582-9900; fax: 1-406-582-9903. The conference rate is US$115 plus tax. Please call +1-406-582-9900 and request a reservation under **MSU Conference Services–Geological Society of America Conference.** Students: Check the meeting website for information on inexpensive residence hall housing.

TECHNICAL PROGRAM

Theme Sessions

T1. **Snoke Session 1: The Eclectic Tectonic Legacy of Arthur W. Snoke—Metamorphic Core Complexes at Age 35.** Allen McGrew, Univ. of Dayton; Josh Schwartz, California State Univ. Northridge; Phyllis Camilleri, Austin Peay Univ.; Walter A. Sullivan, Colby College; Thomas Kalakay, Rocky Mountain College; Cal Barnes, Texas Tech Univ. This session is associated with Field Trip 7.

T2. **Snoke Session 2: The Eclectic Tectonic Legacy of Arthur W. Snoke—Comparative Anatomy and Tectonic Evolution of Continental Margins from the Precambrian to Recent.** Allen McGrew, Univ. of Dayton; Josh Schwartz, California State Univ. Northridge; Phyllis Camilleri, Austin Peay Univ.; Walter A. Sullivan, Colby College; Thomas Kalakay, Rocky Mountain College; Cal Barnes, Texas Tech Univ.

T3. **Precambrian I: Archean and Paleoproterozoic Crustal Evolution of Western Laurentia.** David Mogk, Montana State Univ.; Paul Mueller, Univ. of Florida.

T4. **Precambrian II: Meso- and Neoproterozoic Evolution of Western Laurentia: In Honor of Don Winston.** Paul Link, Idaho State Univ.; Reed Lewis, Idaho Geological Survey. This session is associated with Field Trip 8.

T5. **Session Honoring Kenneth L. Pierce and the Breadth of His Research in Greater Yellowstone.** Cathy Whitlock, Montana State Univ.; Joe Licciardi, Univ. of New Hampshire; Lisa Morgan, USGS; Jennifer Pierce, Boise State Univ.; Cal Ruleman, USGS. This session is associated with Field Trip 11.

T6. **Yellowstone–Snake River Plain–Columbia River Volcanic Province: Geology, Petrology, Geophysics, and Geodynamics.** Bill Phillips, Idaho Geological Survey and Univ. of Idaho; Dan Moore, Brigham Young Univ.–Idaho.

T7. **Recent Advances in Structure, Tectonics, and Metamorphism of the Northern Rockies.** Julie Baldwin, Univ. of Montana; David Foster, Univ. of Florida.

T8. **Geology and Geophysics of the Greater Blue Mountains Province, Salmon River Suture Zone, and Western Idaho Shear Zone: Late Paleozoic through Cenozoic Evolution of a Key Location of the Cordilleran Orogen (Posters).** Todd LaMaskin, Univ. of North Carolina–Wilmington; Joshua Schwartz, California State Univ. Northridge; Basil Tikoff, Univ. of Wisconsin; Reed Lewis, Idaho Geological Survey. This session is associated with Field Trip 1. The organizers request **posters-only** to encourage group discussions.

T9. **Paleogene Topography, Basin Evolution, and Sediment Dispersal in the Northern Rocky Mountain Region.** Bob Schwartz, Allegheny College; Amy Weislogel, Univ. of West Virginia; Marc Hendrix, Univ. of Montana; Theresa Schwartz, Stanford Univ.

T10. **The Early Tertiary Magmatic Firestorm of the U.S. and Canadian Cordillera: Geochemical, Petrological, and Tectonic Constraints.** Richard Gaschnig, Univ. of Maryland; Genet Duke, Arkansas Tech Univ.

T11. **Cenozoic Evolution of the Southwest: From the Relatively Undeformed Colorado Plateau to Central Basin and Range Complexities.** Melissa Lamb, Univ. of St. Thomas; Paul Umhoefer, Univ. of Northern Arizona; Tom Hickson, Univ. of St. Thomas; Sue Beard, USGS Flagstaff.

T12. **Mesozoic Paleogeography of the North American Cordillera.** Joshua Bonde, Univ. of Nevada–Las Vegas; Sean Long, Nevada Bureau of Mines and Geology, Univ. of Nevada; James Schmitt, Montana State Univ.

T13. **Geology and Paleontology of the Two Medicine–Judith River Clastic Wedge.** Jack Horner, Museum of the Rockies and Montana State Univ.; Ray Rogers, Macalester College. This session is associated with Field Trip 10.

T14. **Beyond the Bakken, Three Forks, and Red River "B": New Insights into Williston Basin and Central Montana Trough Petroleum Systems.** Dave Bowen, Vecta Oil and Gas; Dave Eby, Eby Petrography.

T15. **Beyond the Bakken, Three Forks and Red River "B": New Insights into Williston Basin and Central Montana Trough Petroleum Systems (Posters/Core Posters).** Dave Bowen, Vecta Oil and Gas; Dave Eby, Eby Petrography.

T16. **Hydrogeology of the Williston Basin: Toward a Greater Understanding of Aquifer Dynamics, Water Availability, and Risk Potential from Energy Extraction in the United States and Canada.** Kyle Blasche, USGS Montana Water Science Center; Joanna Thamke, USGS Montana Water Science Center.

T17. **Tectonic and Climatic Drivers in Geomorphology and Landscape Evolution.** Jean Dixon, Montana State Univ.

T18. **Paleogene and Neogene Climate of Western North America.** Tom Hickson, Univ. of St. Thomas; Melissa Lamb, Univ. of St. Thomas.

T19. **Holocene Climate of Western North America.** Lesleigh Anderson, USGS; Greg Pederson, USGS; Andrea Brunelle, Univ. of Utah.

T20. **Surface Process Interactions in Riverine Landscapes of the U.S. Rocky Mountains.** Rebekah Levine, Univ. of New Mexico.

T21. **Geomicrobiology: Microbially Mediated Weathering and Biomineralization in Modern and Ancient Environments.** Mark Skidmore, Montana State Univ.; Scott Montross, Montana State Univ.

T22. **Biophysical Interactions in Geomorphology.** Rebecca Manners, Univ. of Montana; Sharon Bywater-Reyes, Univ. of Montana.

T23. **Selenium, Uranium, and Radionuclides: Geology, Biogeochemistry, and Ecosystem Impacts from Mining and Other Activities in the Western United States and Southwestern Canada.** David Naftz, USGS–Montana Water Science Center; Stan Morrison, U.S. Dept. of Energy; Tony Ranalli, USGS–Colorado Water Science Center; Kyle Flynn, Montana Dept. of Environmental Quality.

T24. **EarthScope: Innovative Research, Education, and Outreach Activities.** Steven Semken, Arizona State Univ.

T25. **Teaching the Geology of Western North America.** *Cosponsored by National Association of Geoscience Teachers.* David Mogk, Montana State Univ.; Basil Tikoff, Univ. of Wisconsin; Cathy Manduca, SERC at Carleton College.

T26. **Geologic Maps: Record of the Past, Foundation for the Future (Posters).** Grant Willis, Utah Geological Survey; Susan Vuke, Montana Bureau of Mines and Geology; Reed Lewis, Idaho Geological Survey.

Fossil Tenontosaurus, on display in the Museum of the Rockies in Bozeman, Montana. This specimen was collected in Carbon County, Montana. Photo by Tim Evanson.

T27. **Field-Based Research Experiences for Undergraduates.** *Cosponsored by Council for Undergraduate Research (CUR); National Association of Geoscience Teachers.* Emily Ward-Geraghty, Rocky Mountain College; Derek Sjostrom, Rocky Mountain College; David Mogk, Montana State Univ.; Kim Hannula, Fort Lewis College.

T28. **Teaching Geoscience in the Context of Place and Culture for Sustainability and Diversity.** Steven Semken, Arizona State Univ.; David Mogk, Montana State Univ.

FIELD TRIPS

Pre-Meeting

1. **Hells Canyon to the Bitterroot Front: Transect from the Accretionary Margin Eastward across the Idaho Batholith.** Thurs.–Sun., 15–18 May. US$245. Max: 32. Reed Lewis, Idaho Geological Survey; Keegan Schmidt, Lewis-Clark State College; Richard Gaschnig, Univ. of Maryland; Todd LaMaskin, Univ. of North Carolina–Wilmington; Basil Tikoff, Univ. of Wisconsin; Tor Stetson-Lee, Univ. of Wisconsin; Karen Lund, USGS; Keith Gray, Washington State Univ. This field trip is associated with Theme Session 8.
2. **Sedimentary Record of Glacial Lake Missoula Deposition and Draining, Clark Fork River Corridor from St. Regis to near Drummond, Montana.** Sat.–Sun., 17–18 May. US$195. Max: 20. Larry N. Smith, Montana Tech of The Univ. of Montana; Michelle A. Hanson, Saskatchewan Geological Survey.
3. **Tracking a Big Miocene River across Southwest Montana.** Sat.–Sun., 17–18 May. US$275. Max: 32. James W. Sears, Univ. of Montana.
4. **A Slice through Time: Fifty Years of Field Trips to Hyalite.** Sun., 18 May. US$65. Max: 24. Anthony Hartshorn, Montana State Univ.; Stephanie Ewing, Montana State Univ.; Jean Dixon, Montana State Univ.
5. **Neotectonics and Geomorphic Evolution of the Northwestern Arm of the Yellowstone Tectonic Parabola: Controls on Intra-Cratonic Extensional Regimes, Southwest Montana.** Sun., 18 May. US$75. Max: 40. Cal A. Ruleman, USGS; Mort Larsen, Wyoming State Geological Survey; Michael C. Stickney, Montana Bureau of Mines and Geology.
6. **Regional Setting and Deposit Geology of the Golden Sunlight Mine: An Example of Responsible Resource Extraction.** Sun., 18 May. US$75. Max: 35. Nancy Oyer, Barrick Gold Corp.; John Childs, Childs and Associates.

Post-Meeting

7. **Polyphase Collapse of the Cordilleran Hinterland: Bitterroot and Anaconda Metamorphic Core Complexes of Western Montana—Snoke Symposium Field Trip.** Thurs., 22 May. US$95. Max: 18. Thomas J. Kalakay, Rocky Mountain College; David Foster, Univ. of Florida; Jeff Lonn, Montana Bureau of Mines and Geology. This field trip is associated with Theme Session 1.
8. **Mesoproterozoic Tectonics and Sedimentation along the Southern Margin of the Belt Basin: In Honor of Don Winston.** Thurs., 22 May. US$95. Max: 25. David Mogk, Montana State Univ.; Jim Schmitt, Montana State Univ.; Zach Adam, Montana State Univ.; Paul Mueller, Univ. of Florida. This field trip is associated with Theme Session 4.
9. **The World-Class Talc Deposits of Southwestern Montana.** Thurs., 22 May. US$95. Max: 35. John Childs, Childs and Associates; Erika Bartlett, Imerys Talc; Michael T. Cerino, Barretts Minerals Inc.; Helen B. Lynn, Childs Geoscience Inc.; Sandra Underwood, Childs Geoscience Inc.; Chad P. Walby, Childs Geoscience Inc.; Zackary S. Wall, Childs Geoscience Inc.
10. **Geology and Paleontology of the Two Medicine–Judith River Clastic Wedge: Field Trip to The Rocky Mountain Front and North-Central Montana, Including Type Sections of The Two Medicine and Judith River Formations.** Thurs.–Sat., 22–24 May. US$375. Max: 19. Jack Horner, Museum of the Rockies and Montana State Univ.; Ray Rogers, Macalester College; David Lageson, Montana State Univ.. This field trip is associated with Theme Session 13.
11. **Glacial and Quaternary Geology of the Northern Yellowstone Area, Wyoming and Montana.** Thurs., 22 May. US$75. Max: 30. Ken Pierce, USGS. This field trip is associated with Theme Session 5.

OPPORTUNITIES FOR STUDENTS

Mentor Programs

Roy J. Shlemon Mentor Program in Applied Geoscience Luncheon. *Cosponsored by the GSA Foundation.* Mon., 19 May, 11:30 a.m.–1 p.m. Discuss career prospects and challenges with professional geoscientists over a FREE lunch.

John Mann Mentors in Applied Hydrogeology Program Luncheon. *Cosponsored by the GSA Foundation.* Tues., 20 May, 11:30 a.m.–1 p.m. Discuss career prospects and challenges with professional geoscientists over a FREE lunch.

▶ *NEW!* **Communicating Science: Tools for Scientists.** *Cosponsored by the GSA Geology and Society Division.* Mon., 19 May, 8–11:30 a.m. US$15; includes continental breakfast. Max.: 30. Hone your public communication and outreach skills.

▶ *NEW!* **GSA Student Feedback Session.** *Sponsored by GSA Council.* Wed., 21 May, lunchtime, brownbag. Student attendees are invited to bring their lunch to this event and discuss the state of the Society and its new initiatives. Moderated by a member of the GSA Executive Board. Refreshments provided.

Travel Grants

Application deadline: 14 April

Please review the eligibility guidelines posted online at www.geosociety.org/grants/travel.htm. **You must be registered for the meeting BEFORE you can apply.**

2014 GSA Section Meeting Mentor Programs

Plan now to attend a Roy J. Shlemon Mentor Program in Applied Geoscience and/or a John Mann Mentors in Applied Hydrogeology Program at your 2014 Section Meeting to chat one-on-one with practicing geoscientists. These volunteers will answer your questions and share insights on how to get a job after graduation.

FREE lunches will be served at these mentor programs. Check the meeting website and program to confirm time and location. A reminder will be included on all student badges at the onsite registration desk.

The popularity of these programs means that space is limited, so plan to arrive early, because lunch is first-come, first-served. For further information, contact Jennifer Nocerino at jnocerino@geosociety.org.

South-Central Section

Fayetteville, Arkansas, USA
Shlemon luncheon: Mon., 17 March
Mann luncheon: Tues., 18 March

Northeastern Section

Lancaster, Pennsylvania, USA
Shlemon luncheon: Sun., 23 March
Mann luncheon: Mon., 24 March

Southeastern Section

Blacksburg, Virginia, USA
Shlemon luncheon: Thurs., 10 April
Mann luncheon: Fri., 11 April

North-Central Section

Lincoln, Nebraska, USA
Shlemon luncheon: Thurs., 24 April
Mann luncheon: Fri., 25 April,

Joint Meeting: Rocky Mountain and Cordilleran Sections

Bozeman, Montana, USA
Shlemon luncheon: Mon., 19 May
Mann luncheon: Tues., 20 May

NEW!

GSA GEOSCIENCE CAREER PROGRAM WORKSHOP

Students: Are you about to embark on the search for a job? Or are you currently in the job market and want to increase your chances? Would you like some feedback on your résumé and some pointers on approaching your interview? The new GSA Geoscience Career Program will be running free workshops at each of the 2014 Section Meetings designed to help you begin this process. We will discuss cover letters, CVs/résumés, job hunting skills, and job market statistics.

www.geosociety.org/mentors/sectionSched.htm

P. Geoffrey Feiss, GSA Foundation President

GSA Member Support at Work: GeoCorps™ America

GeoCorps™ America is a steadily growing program that places all levels of geoscientists—students, professionals and retirees—in temporary positions with natural resource agencies. Agency staff select projects, many field based, that require expertise in the geosciences. GSA program staff recruit applicants from among the Society's membership to place the most qualified applicant in posted positions. Participants receive a stipend and living allowance and work side-by-side with agency field staff, receiving invaluable training and experience. In their roles as interpreters and researchers, agencies rely on GeoCorps participants to transfer their knowledge of geology through visitor education, resource management, site protection, and geologic hazards mitigation.

Since 1997, GeoCorps has placed more than 1,000 geoscientists in temporary positions at 120 national parks, monuments, forests, and U.S. Bureau of Land Management sites (see graph). Funding for GeoCorps comes from GSA, GSA members, and participating agencies. Support from GSA members has been instrumental in helping the program grow, especially in recent periods of budget uncertainty.

For example, thanks to generous support from GSA member Sally Newcomb, Denali National Park will host five GeoCorps participants in 2014. Newcomb's continuous support has secured a place for GeoCorps in Denali National Park's annual resource planning.

GeoCorps America is a valuable partnership between GSA, natural resource agencies, and the public. Thank you for your support of this and other education and outreach programs!

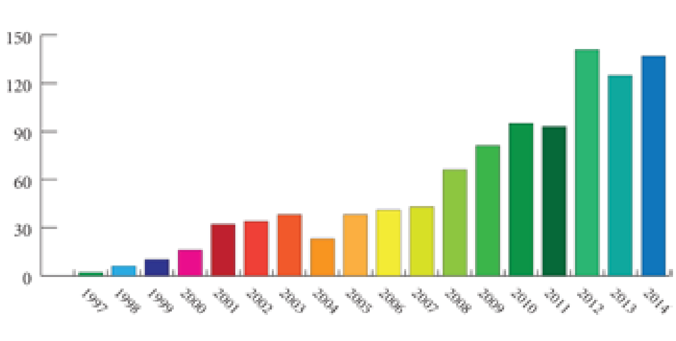
For more information, go to www.geosociety.org/geocorps/ or contact Matt Dawson at mdawson@geosociety.org or +1-303-357-1025.

If you'd like to support GeoCorps through a gift of any amount, please visit the GSA Foundation webpage dedicated to Education and Outreach programs at www.gsafweb.org/programsupport.html, or contact Chris Tallackson at ctallackson@geosociety.org or +1-303-357-1007.

GEOCORPS™ AMERICA PARTICIPANT PROFILE

Lisa Merkhofer worked at Denali National Park and Preserve in 2012, where her primary duty was to continue a paleontological inventory of the Cantwell Formation, searching for dinosaur tracks, plant impressions, invertebrate traces and burrows, and fossil bacterial mats that offer a valuable window to the past. With the help of her GeoCorps partner, Tyra Olstad, she used trends in previously recorded sites to prioritize new areas to inventory. Merkhofer and Olstad mapped many kilometers of backcountry, photographing specimens and reporting details such as fossil preservation quality, abundance, as well as site accessibility and likelihood of natural or human disturbance.

GeoCorps™ America Participants



2012 GeoCorps participant Lisa Merkhofer, Denali National Park and Preserve.

About People

GSA member **Stacia Gordon** will receive the European Geosciences Union's 2014 Young Scientist Award for the Structural Geology and Tectonics Division. She will travel to Vienna, Austria, in April to receive the award and to present a lecture concerning her research on plate tectonics and partial melting of rocks deep below Earth's surface.

GSA Fellow **Kerry Sieh** has been named the Seismological Society of America's Harry Fielding Reid medalist for his pioneering work and leadership. Sieh revolutionized the study of earthquakes by spearheading the development of the field of paleoseismology. The Harry Fielding Reid Medal for outstanding contributions in seismology and earthquake engineering will be presented at the 2014 SSA annual meeting in April in Anchorage, Alaska, USA.

Learn more and catch up on other member news at **www.geosociety.org/news/memberNews.htm.**

Top and bottom: Cassi Knight, Grand Canyon National Park, 2013. Middle: Erin Smith, Mount Rainier National Park, 2013.

2013–2014 GSA-USGS Congressional Science Fellow Report

Anna K. Mebust

Policy, Politics, and Procedure

I walked into my first day of orientation as a science policy fellow full of excitement and enthusiasm, ready to learn how to leverage my scientific background in the policy-making process. I had been doing air quality–related research throughout my undergraduate years and my Ph.D., but over the years I became increasingly interested in seeing how that work could be useful at the policy level. I was extremely honored to receive the 2013–2014 GSA-USGS Congressional Science Fellowship and eager to see what life working on Capitol Hill (or "the Hill") would be like.

One of the lessons from orientation that resonated most with me came from Judy Schneider, a specialist on Congress for the Congressional Research Service, who shared some of her infinite wisdom on what makes Congress tick. Her mantra: "Policy, politics, and procedure." As outsiders of Congress, and especially as scientists, we have focused on what makes good policy, but in Congress itself, it is important to remember that policy is usually subject to both politics and procedure. As it turned out, an eventful and historic fall season on the Hill has provided some revealing examples.

First, though, I should describe the incredible experience that is the fellowship placement process. It begins with a mixer between the Congressional fellows and staffers from interested offices. After the mixer, we can begin to schedule interviews with any interested office (both personal and committee offices, within the House or the Senate). This is a grueling process, with several interviews each day—on my busiest days, I met with five separate offices—and continuing for several days in a row, but it is an extraordinary opportunity to learn about the different offices and connect with staff across the Hill. One of the most memorable moments for me was chasing down a staffer I had never met in the Metro station to introduce myself. It turned out to be a great decision, because I ended up choosing to work with that staffer in the personal office of Senator Bernie Sanders from Vermont.

I felt that Senator Sanders's office was a perfect match for me in many ways. The senator has been an outspoken advocate for action on climate change, an area that was high on the list of topics I wanted to work on during my time in Congress. He is also the only senator who sits on both the Senate Energy and Natural Resources Committee and the Environment and Public Works Committee, providing the opportunity to work on an extremely broad range of scientific issues—another priority of mine. Perhaps most importantly, the office atmosphere was exactly what I was looking for. I am thrilled that I found such a great office to work in and am looking forward to what will hopefully continue to be an educational and illuminating year.

Now, back to policy, politics, and procedure. As you might know, October brought some unexpected challenges to the Hill. One of Congress's primary jobs is to pass the yearly appropriations bills that provide funding for much of the federal government. If the two houses can't work through the appropriations process in time, they have the option to pass what is known as a "continuing resolution," which continues funding at previous levels to give Congress some time to work out their differences. In this Congress, when 1 October rolled around, the appropriated funds ran out and no continuing resolution was passed, leading to the first federal government shutdown in 17 years. Very few people would argue that shutting down the government is a wise policy choice, but in this case, politics won out over policy.

My first full day in the office was 30 September, so the shutdown heavily shaped my first few weeks on the job. Many members of our staff were furloughed. The remaining staff, myself included, all took turns answering phones and working the front desks. These tasks are not normally part of a fellow's duty, but I was extremely grateful for the opportunity to experience that part of working in a Congressional office. I gained a lot of respect for the staffers who sit at those desks every day—it is not an easy job. Outside of answering phones, working during the shutdown was far quieter than I had expected for my first weeks on the Hill, as most of our meetings were canceled and there were very few committee hearings or briefings to attend. I was pleased when Congress passed a continuing resolution and things could get back to (relatively) normal, both for me and for the many employees in the federal government who had been furloughed.

A few weeks later, we were provided with a perfect example of the importance of procedure in the inner workings of the Senate. Some of you are probably familiar with the "filibuster," a procedural strategy used by the minority party to block votes. In November, Senate Majority Leader Harry Reid decided to use another procedural tactic, the "nuclear option," to eliminate the filibuster for nominee confirmations (excluding Supreme Court nominees). With no option to block votes, the minority party chose to use another procedural technique, slowing down the confirmations by refusing to give "unanimous consent" to temporarily change the rules to speed up the votes. As a result, for a few days the Senate had votes at odd times, even in the middle of the night. These procedural battles can be very difficult for those

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outside of Congress (and even some on the Hill) to understand, but they are an important part of how the system works.

So, it has been an exciting start to my fellowship year. After budget battles and the nuclear option, where are we headed next? Who knows—as they told us during orientation, every year is different, and often unpredictable. No matter what happens, I know this much: I am in for one of the most fascinating and chaotic years of my life. Keep in touch if you'd like to know how things are going in this mysterious world ruled by policy, politics, and procedure.

This manuscript is submitted for publication by Anna Mebust, 2013–2014 GSA-USGS Congressional Science Fellow, with the understanding that the U.S. government is authorized to reproduce and distribute reprints for governmental use. The one-year fellowship is supported by GSA and by the U.S. Geological Survey, Department of the Interior, under Assistance Award No. G13AP00095. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. government. Anna is working in the office of Senator Sanders (I-VT) and can be reached at Anna_Mebust@sanders.senate.gov.

ROCK STARS

Laurence L. Sloss and the Sequence Stratigraphy Revolution

Robert H. Dott, Jr., *Department of Geoscience, University of Wisconsin, Madison, Wisconsin 53706, USA*

Stratigraphy is one of the oldest branches of geology, dating back 200 years to William Smith and Georges Cuvier at the beginning of the nineteenth century. It was then that the value of fossils for subdividing and correlating strata was first demonstrated. The new method served well for 150 years, but by the mid-twentieth century, detailed studies showed that fossil occurrences were dependent not only on time, but also on environment. As changes to environment occurred, the fossil animals migrated and so could vary in age laterally, contradicting the long-held assumption of strict time dependence of species.

By the 1930s, Laurence L. Sloss noted that stratigraphy was beset with "stupefying arguments" about abstract time versus actual rocks and how to classify such things. The concept of time-stratigraphic divisions addressed some of the concerns, and bio-, litho-, and chrono-stratigraphy were separately defined. For folks who delighted in describing and classifying, there was plenty of work, but for others, frustration prevailed. Sloss entered our profession during this period and, to quote him, "My enthusiasm for paleontologic taxonomy expired even as I was completing a dissertation on Devonian corals" (1984, p. 3). He was soon to discover several important unconformities in the Montana region, which did not conform to any classical, fossil-based stratigraphic divisions, yet they seemed to divide the rock record into meaningful, natural packages. Thus, the germ of sequence stratigraphy was born.

WHO WAS LAURENCE L. "LARRY" SLOSS?

Sloss was raised in the San Francisco Bay Area. His grandfather was a forty-niner who passed up gold in favor of seal skins for a fortune. "He amassed a considerable fortune by killing nearly all the seals on the Pribilof Islands—an enterprise unimpeded by a Sierra Club and not even requiring an environmental impact statement" (1980 William H. Twenhofel Medal acceptance speech, *in* Anonymous [1999, p. 79]). Grandpa returned to California and used his fortunes to create a successful fruit-raising business. Young Sloss followed his friends to Stanford University, where he discovered geology. His summer field course was taught in western Nevada by distinguished petrologist, Aaron C. Waters

Figure 1. Stanford Field Course, 1933; Sloss: front left; Waters: standing (courtesy Stanford University).

(Fig. 1). Sloss told me that Waters was a bit of a martinet, who made good on his threat to leave them to the coyotes if they did not show up at the designated spot at exactly 4 p.m. He remembered "arriving late one day at the pick-up point with empty canteens to see a cloud of dust marking the passage of the camp transport truck… We made it back to camp after dark." He also remembered that Waters snored terribly, and one night the boys carefully moved his cot right next to the spring pool where they were camped. Sure enough one great snore was suddenly drowned out in the wee hours as Waters rolled over.

In spite of what Sloss described as a desultory undergraduate career, he was admitted to the University of Chicago graduate program (having been rejected by Harvard) where he completed a paleontological dissertation directed by Professor Carey Croneis. While Sloss was honeymooning, Croneis found him a job in Montana. During the academic year, he was to teach stratigraphy at the School of Mines in Butte, and during summers he would work for the Montana Bureau of Mines. He felt very lucky because in 1937 jobs were mighty scarce.

BIRTH OF THE SEQUENCE CONCEPT

It was during his seven years in Montana that Sloss first recognized those regional unconformities, which would become the basis for sequence stratigraphy (Fig. 2). Several petroleum companies were actively exploring in the region, and they became interested in his work. Sloss became especially well acquainted with Gulf Oil Company geologist Max Littlefield, who introduced him to geophysical techniques for studying stratigraphy in the subsurface.

In 1947, Sloss accepted a faculty position at Northwestern University, where he joined Edward C. Dapples and former University of Chicago associate, William C. Krumbein. Thus was formed an unusually fruitful team of sedimentary geologists, which was to have a major impact upon the field during the next four decades (Fig. 3). Dapples and Sloss knew regional stratigraphy well and found that they had observed separately several of the same unconformities in different parts of the central craton. Krumbein was a pioneer in quantification of sedimentary data and was trying to develop a way to provide some quantitative rigor to the analysis of sedimentary facies. He needed some basis for

Figure 2. Sloss leading a pack train in Montana, 1944 (courtesy Northwestern University).

Figure 3. The Northwestern triumvirate in 1950: left to right: Sloss with trademark pipe and bow tie, Krumbein, and Dapples (courtesy Northwestern University).

subdividing the stratigraphic record into *operational units* for facies mapping, so the trio seized upon those unconformity-bounded packages of strata as such units and named them stratigraphic *sequences.* To emphasize the distinction of their sequences from the conventional European fossil-based stratigraphic subdivisions, they cleverly chose the names of Native American tribes indigenous to the areas where a given sequence was best represented. Thus the Sauk Sequence was named for Sauk County, Wisconsin. At first, four sequences were so named, which approximately spanned all of the Paleozoic systems. Later, as they became more acquainted with the younger record toward the margins of the craton, two more sequences were named (Fig. 4).

In 1948, the Geological Society of America sponsored a symposium on sedimentary facies, the results of which were published in six papers as GSA Memoir 39, *Sedimentary Facies in Geologic History.* It was in this timely volume that the Northwestern scheme for facies analysis was introduced. Sloss told me that their paper violated Krumbein's Rule that a published paper should present only one new idea; they had introduced not only the new quantitative facies analysis, the main topic, but also the new concept of stratigraphic sequences.

Sequence stratigraphy, like many new ideas, was not met with immediate acclaim. Most of the profession's members did not quite know what to think of it. One distinguished member of the symposium audience, Philip B. King, complimented their statistical approach to facies, but then declared, "Why should these authors then proceed to detract from their excellent technique by superimposing on it the wholly unwarranted 'operational units,' which are newly named and which have no relation to time-stratigraphic units? The reasons given for adopting such units are specious, the new names confuse rather than illuminate" (Longwell, 1949, p. 169). This was a common reaction.

Sloss and his two associates had also adopted the sedimentary rock classification of Paul D. Krynine, and much of that author's ideas about sedimentary tectonics. Rather than being flattered, however, Krynine remarked in a 1951 paper, "They (Sloss, Krumbein, and Dapples) quote, but do not utilize my ideas of the diastrophic and geosynclinal cycle of sedimentation" (p. 745), adding, "The very moderate success of their effort suggests that the proper genetic bridge between sedimentation and tectonics has not quite been established" (p. 746). Apparently Krynine harbored little respect for stratigraphy, because two of his former students quoted him as saying that stratigraphy represents the "Complete triumph of terminology over facts and common sense" (Folk and Ferm, 1966, p. 853).

When I questioned Sloss in 1996 about influences upon the original conception of sequence stratigraphy, he acknowledged that the paleogeologic or subcrop maps of A.I. Levorsen and others and the novel ideas about cratonic stratigraphy of E.O. Ulrich during the 1930s certainly had been influential, as had the later stratigraphic thinking of Harry E. Wheeler. Sloss and Wheeler had overlapped at Stanford and had been associated as co-consultants to oil companies during the 1950s, exploring the western states, with many opportunities to exchange ideas. Sloss emphasized, however, that "the growing scope of stratigraphic investigations and, most importantly, the emergence of subsurface data, made it (sequence stratigraphy) inevitable."

SEISMIC SEQUENCE STRATIGRAPHY

In the late 1960s, Sloss and Dapples had several exceptional students, notably Peter Vail, Robert Mitchum, and John Sangree, who completed dissertations involving Pennsylvanian strata. They became aware that glacial eustatic changes of sea level could have been responsible for the numerous widespread unconformities in the famous cyclothems. Following receipt of their degrees, these men joined an Exxon research group, which was to develop modern seismic stratigraphy. They adopted and greatly refined their mentors' sequence stratigraphy to the interpretation of subsurface seismic data. They recognized similar successions of sequences and unconformities on different, widely separated continental margins, which implied some global cause, perhaps glacial eustatic fluctuations.

Their approach recognized shorter-duration successions than Sloss' original sequences. Whereas each of his six craton-wide sequences represented hundreds of millions of years, the seismic

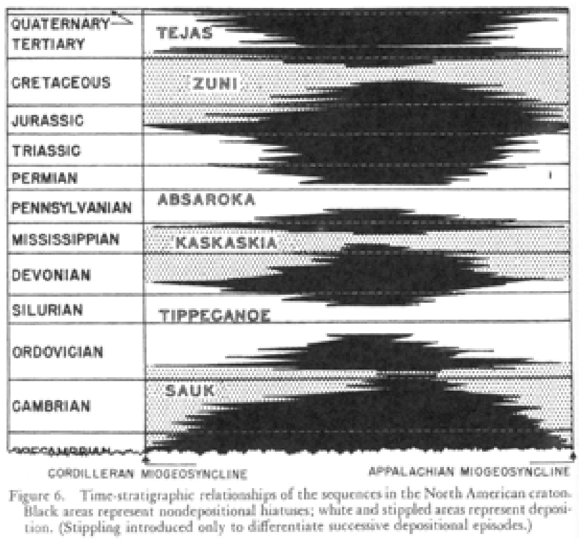

Figure 4. The sequences in 1963 (Sloss, 1963, fig. 6, p. 110).

sequences typically represent only thousands to a few million years. History has shown that the concepts developed for seismic stratigraphy have widespread application to outcrop geology as well as to the subsurface, and so it is this refined sequence stratigraphy that has so revolutionized modern stratigraphy.

In 1984, Sloss had this to say about his intellectual children: "This group was pre-adapted to recognize unconformity-bounded units on reflection seismic records and they are deeply impressed by the apparent global synchrony of stratigraphic patterns clearly related to the freeboard of continental margins. … They find that they sleep well when they place their faith in eustatic sea levels and dream pleasant dreams when glacial controls on eustatics can be invoked" (p. 9–10).

To his grave, Sloss remained assured that tectonics, presumably plate tectonics, somehow controlled the sequences (1988). Recent seismic tomography shows large-scale heterogeneity in the mantle beneath North America, which is being interpreted as due to relict subducted slabs. Regardless of their cause, is it not possible that isostatic adjustments of the overlying crust as plate motions carry the continent over such heterogeneities could explain the warping of cratonic arches and basins?

HONORS

Sloss received many honors, including the Penrose Medal of the Geological Society of America (GSA) and the Twenhofel Medal of the Society for Sedimentary Geology (SEPM). In 1999, the GSA Sedimentary Division created the Sloss Medal in his honor. He was president of GSA, SEPM, and the American Geoscience Institute, and he served on many professional committees and commissions. Sloss was a geological statesman, philanthropist, and an influential teacher who always encouraged the young.

I conclude with Sloss' own droll remarks from his 1980 Twenhofel Medal acceptance speech: "I wish I could leave you with… some trenchant maxim that would make me seem a worthy role model for rising young geologists; instead, all that runs through my mind is that a lack of virtue does not necessarily lead to a lack of rewards, that procrastination saves time (the problem may go away) and, that there **is,** indeed, a free lunch, and I just had one" (*in* Anonymous, 1999, p. 80).

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ECONOMIC GEOLOGY
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The Nevada Bureau of Mines and Geology (NBMG) at the University of Nevada, Reno (UNR), seeks applicants for a tenure-track faculty position focused on hydrothermal mineral deposits. NBMG is a research and public service unit of UNR and the state geological survey. Managed as part of the Mackay School of Earth Sciences and Engineering in the College of Science at UNR, NBMG functions as an academic unit, and its principal scientists are tenure-track faculty members. Nevada is one of the most exciting regions in the world to do research in the geosciences, and the best in the U.S. for the study of hydrothermal mineral deposits.

Interested applicants must have a doctorate in geology or a related geoscience field by the time of hire and a demonstrated record of research on topics related to hydrothermal mineral deposits as indicated by dissertation research or peer-reviewed publications. Excellent communication skills, as demonstrated in written application materials; commitment to public service; potential for, or established record of publications; and ability to attract funding are essential. Doctoral research must include one or more of the following disciplines: economic geology, structural geology, igneous petrology, and geochemistry.

Additional preferred qualifications include (1) industrial or academic experience in hydrothermal minerals deposits, particularly in field-based studies in a variety of geological settings; (2) expertise in structural geology, geologic mapping, and active hydrothermal systems (geothermal activity); (3) research productivity with publications in the peer-reviewed literature; (4) achievable plans for funded research on Nevada-focused topics in economic geology and geothermal energy, as described in the applicant's letter of interest; and (5) both an understanding of and interest in contributing to the role of a state geological survey on issues related to mineral deposits and other resources, beyond basic scientific research.

Position responsibilities and expectations include (1) working independently as well as collaborating with NBMG faculty-staff, faculty in other geoscience units at UNR and UNLV, and others in industry and government in developing funded projects and conducting research; (2) contributing to the development of datasets and reports on Nevada's mineral and energy resources, including resource assessments; (3) communicating effectively with the public and community leaders regarding the geology of Nevada and its mineral and energy resources; (4) focusing research on mineral deposits in Nevada; and (5) supervising graduate students and teaching undergraduate and graduate classes.

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Applicants should provide a letter of application that addresses their experience and teaching and research interests, a curriculum vitae, and contact information for three references. Please send materials electronically to Dr. Diane R. Smith, Chair, Dept. of Geosciences, at geos.search@trinity.edu. Consideration of applications will begin on 1 Feb. and continue until the position is filled. Trinity University is an equal opportunity employer. Minority and women candidates are encouraged to apply.

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