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Boulders of the Vastitas Borealis Formation: Potential origin and implications for an ancient martian ocean

2014 Section Meeting Calendar

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Fayetteville, Arkansas, USA
17–18 March 2014
University of Arkansas
Local Committee chair: Steve Boss
Early registration deadline: 10 Feb. 2014

NORTHEASTERN SECTION
Lancaster, Pennsylvania, USA
23–25 March 2014
Lancaster Marriott
Local Committee co-chairs: Noel Potter and Roger Thomas
Early registration deadline: 18 Feb. 2014

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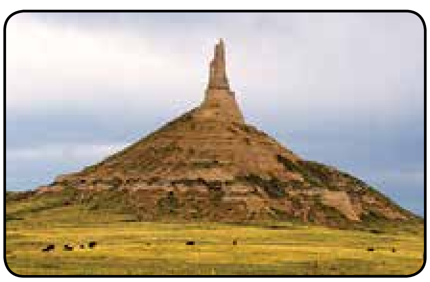

NORTH-CENTRAL SECTION
Lincoln, Nebraska, USA
24–25 April 2014
Cornhusker Marriott
Local Committee chair: Matt Joeckel
Early registration deadline: 24 Mar. 2014

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
Abstracts deadline: 11 Feb. 2014
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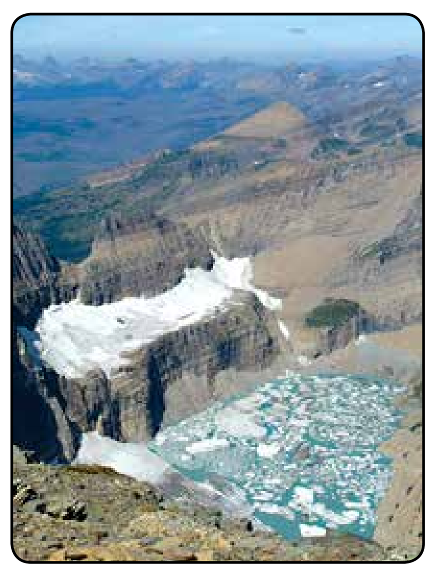

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Featured Articles

SCIENCE:

Cover: Recently documented terrestrial, deep-water analogies seem to fit as part of a puzzle suggesting that a Late Hesperian–Early Amazonian martian ocean once existed in the northern plains of Mars. Rows of coupled, puzzle-pieces from top to bottom showcase the analogies between martian teardrop-shape islands (left) and terrestrial erosional-shadow remnants (right); martian large-scale polygonal terrains (right) and terrestrial deep-water polygonal fault systems (left); martian high-albedo mounds (left) and terrestrial deep-water mud volcanoes (right); and martian boulders from the VBF (right) and terrestrial deep-water megablocks (left). The question remains: Are there any other terrestrial, deep-water analogies awaiting to be discovered? See related article, p. 4–10.

GROUNDWORK:

GSA News

Boulders of the Vastitas Borealis Formation: Potential origin and implications for an ancient martian ocean

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ABSTRACT

The hypothetical existence of a martian ocean that is based on identification of alleged paleoshorelines has been heavily contested during recent years. Despite the controversy surrounding the paleoshoreline interpretation, additional evidence supporting the idea of a late Hesperian–early Amazonian martian ocean has recently been documented in areas that were potentially covered by this body of water. Most of these observations have been made by the establishment of analogies between martian features within the northern plains and depositional elements from deep-water terrestrial environments (e.g., teardrop-shaped islands, large-scale polygonal terrains, and high-albedo mounds). This paper showcases a new terrestrial, deep-water analogy that also supports the existence of an ancient martian ocean. Boulder-size rocks that are contained within the Vastitas Borealis Formation (VBF) on the northern plains of Mars are compared with boulder- and kilometer-scale blocks that have been transported subaqueously as part of mass-transport events in a multitude of terrestrial deep-water environments. These observations suggest that meter-scale rocks that make up part of the VBF might have been emplaced by catastrophic mass-transport events similar to those documented within continental margins on Earth.

INTRODUCTION

The existence of an ancient martian ocean on the northern plains of Mars was originally postulated on the basis of the identification of paleoshorelines using *Viking Orbiter* images (Parker et al., 1989, 1993); however, this line of evidence has been heavily questioned because these contacts have significant variations in elevation, and some of them have turned out to be of volcanic origin (Carr and Head, 2003). The Vastitas Borealis Formation (VBF) is an upper Hesperian to lower Amazonian unit that was deposited in the northern martian lowlands and that is contemporaneous with the genesis of outflow channels (Tanaka and Scott, 1987; Kreslavsky and Head, 2002). The hypothetical existence of an ocean occupying the northern plains of Mars during late Hesperian–early Amazonian time (Baker et al., 1991) would imply that the VBF was deposited under marine conditions (Carr and Head, 2003). The VBF occupies 45% of the northern lowlands, containing knobby, mottled, and grooved terrains that have been linked by some researchers to marine processes (Kreslavsky and Head, 2002). Despite the marine hypothesis, different origins have been postulated to explain the occurrence of the VBF, and this topic remains under the scrutiny of the planetary science community (Carr and Head, 2003; McEwen et al., 2007). The paleoshoreline controversy (Parker et al., 1989, 1993) has driven the search for evidence of an ancient martian ocean to deposits located on the northern plains rather than at the outer margins of this hypothetical body of water (Carr and Head, 2003). In recent years, significant progress has been made in documenting terrestrial analogues for the deposits located on the northern plains of Mars that are consistent with the existence of a late Hesperian–early Amazonian martian ocean. These terrestrial analogues include (1) a resemblance between teardrop-shaped islands located on the downstream end of outflow channels on Mars and erosional shadow remnants documented in deep-water terrestrial environments (Moscardelli and Wood, 2011); (2) similarities between large-scale polygonal terrains on Mars and deep-water polygonal fault systems on Earth (Cooke et al., 2011; Allen et al., 2013; Moscardelli et al., 2012); and (3) comparisons between high-albedo mounds in Acidalia Planitia and terrestrial submarine mud volcanoes (Allen et al., 2013; Oehler and Allen, 2012) (Fig. 1). This work seeks to showcase an additional terrestrial, deep-water analogy that also supports the hypothetical existence of a late Hesperian to early Amazonian martian ocean. Boulder-size rocks contained within the VBF (Fig. 2) are compared with blocks and boulders that have been seismically imaged in deep-water terrestrial environments (Fig. 3) (Lee et al., 2004; Alves, 2010; Dunlap et al., 2010; Jackson, 2011, 2012) and reported in outcrop locations (Macdonald et al., 1993; Slatt et al., 2000; Dykstra et al., 2011) (Fig. 4). This new analogy is also placed into a broader context that supports a subaqueous origin for the VBF.

TERRESTRIAL MASS-TRANSPORT DEPOSITS

Submarine mass-transport deposits (MTDs) are generated by the action of gravity-driven processes affecting sediments within continental margins. Mass-transport events are linked to laminar flows, but not to Newtonian flows, which are commonly associated with the formation of turbidites (Dott, 1963; Nardin et al., 1979; Moscardelli and Wood, 2008). Slides, slumps, and debris flows are constituents of MTDs and can co-occur in the same event or depositional unit (Moscardelli and Wood, 2008). Mass-transport events have a high recurrence rate on continental margins and can remobilize huge volumes of sediments; as a consequence, associated MTDs often form a significant component of the stratigraphic column in both ancient and modern deep-water successions (Moscardelli and Wood, 2008). Grains

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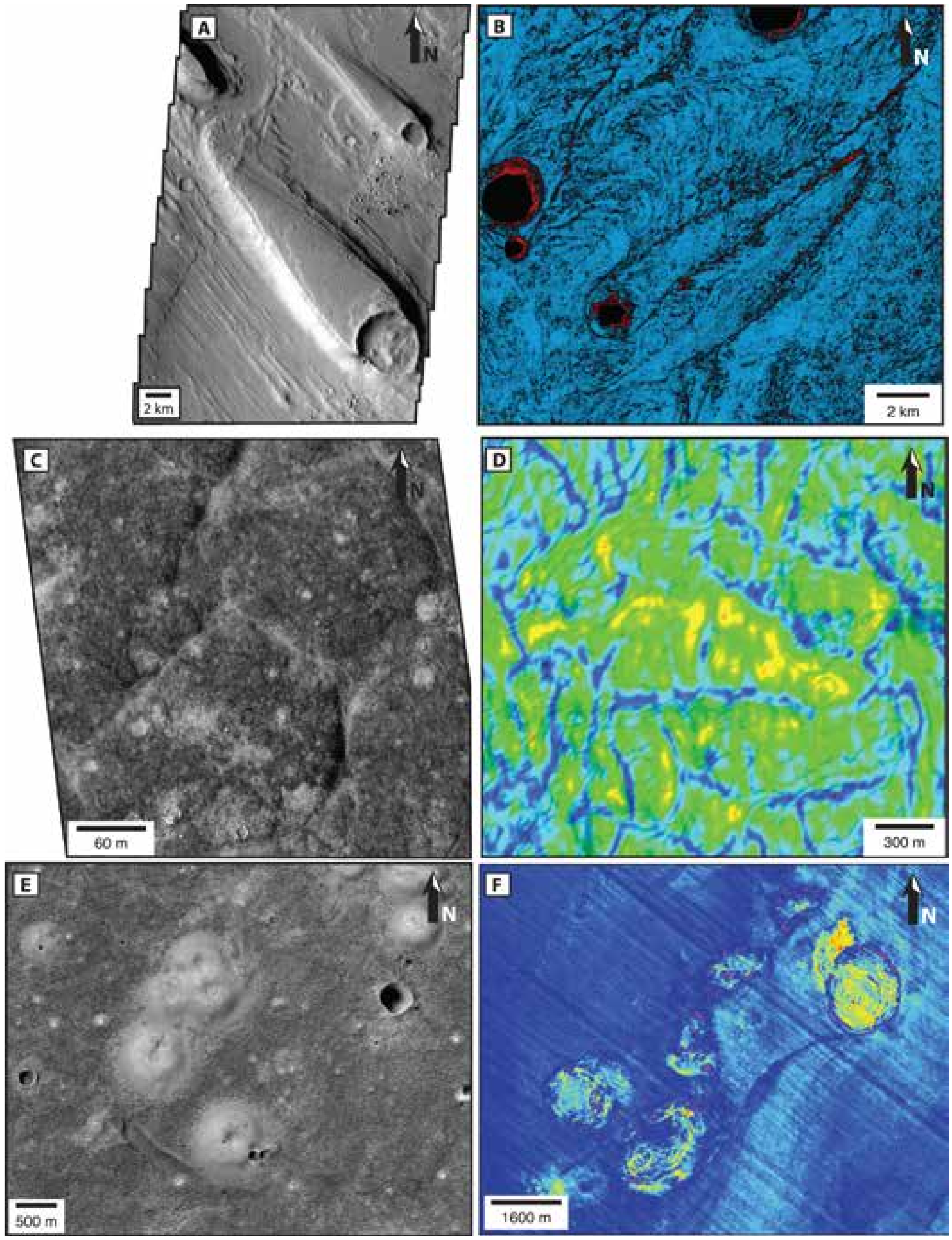

Figure 1. (A) Teardrop-shaped islands (TSIs) on downstream end of Ares Vallis (THEMIS V01786010). (B) Erosional shadow remnants (ESRs) in a deep-water Pliocene–Pleistocene stratigraphic succession of eastern offshore Trinidad (root-mean-square [RMS] attribute extraction map). (C) Large-scale polygonal terrains in Acidalia Planitia (HiRISE PSP_006636_2260). (D) Deep-water polygonal fault system in offshore Norway, Brygge Formation (RMS attribute extraction map). (E) High-albedo mounds in Acidalia Planitia (HiRISE PSP_008522_2210). (F) Mud volcanoes on the slope region of eastern offshore Trinidad (RMS attribute extraction map).

within mass-wasting events are transported and sustained by a muddy matrix in a laminar flow, and finding boulder- to kilometer-size blocks contained within MTDs is not uncommon (Macdonald et al., 1993; Lee et al., 2004; Alves, 2010; Dunlap et al., 2010; Dykstra et al., 2011; Jackson, 2011, 2012). A good example of boulder-size rocks embedded within the muddy matrix of a MTD can be observed in the outcrops of the Carboniferous Guandacol Formation in the Pangazo Basin, Argentina (Dykstra et al., 2011). The Guandacol MTD, 120 m thick, contains granule- to boulder-size clasts of granitoid and metamorphic basement rocks, as well as allochthonous blocks of sandstones. The sizes of the sandstone blocks can vary from a few meters to tens of meters in width and a few meters to ~10 m in thickness. These boulders and blocks are interpreted as having been removed from underlying units and incorporated into the mass-transport flow during emplacement of the Guandacol MTD (Dykstra et al., 2011). Spectacular MTD blocks also crop out as part of the Ablation Point Formation on Alexander Island. This

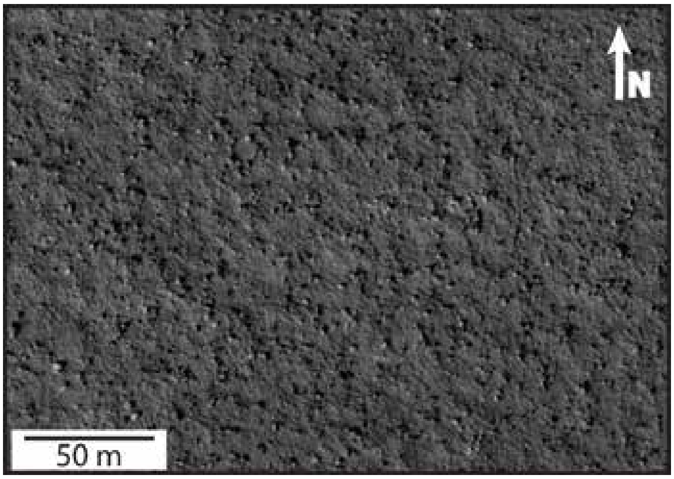

Figure 2. Knobby terrains in Arcadia Planitia (HiRISE ESP_019853_2410).

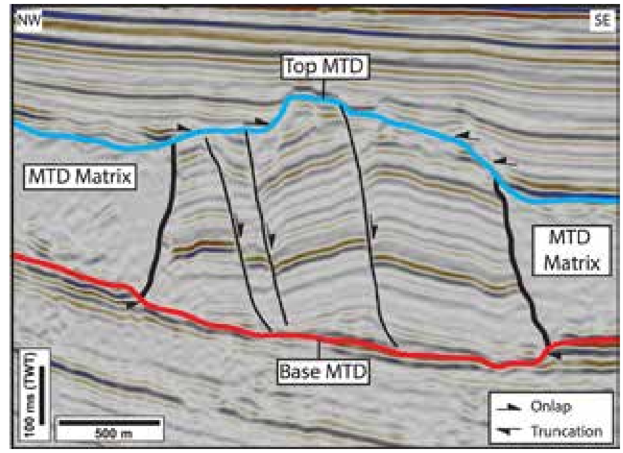

Figure 3. Cross section highlighting character of megablocks and other submarine mass-transport deposit (MTD) seismic facies in the Santos Basin (offshore Brazil). Image facilitated by Christopher Jackson and courtesy of CGGVeritas. TWT—two-way travel time.

unit forms part of the Jurassic–Cretaceous Fossil Bluff Group in the Antarctic Peninsula (Macdonald et al., 1993). The Ablation Point MTD, which can reach a total thickness of 400 m, contains abundant resedimented blocks of older volcanic rocks and turbidite sandstones. More accessible outcrops containing megablocks with variable sizes are located in the Pennsylvanian Jackfork Group of south-central Arkansas, where blocks of resedimented sandstone turbidites crop out in a variety of locations (Slatt et al., 2000) (Fig. 4). Individual blocks can reach >25 m in thickness and >100 m in length. Identification of MTD blocks in outcrops can be challenging because the scale of exposure might not be adequate for recognition of the presence of allochthonous blocks that can be hundreds of meters thick and kilometers long (Macdonald et al., 1993) (Fig. 5).

More recently, acquisition of high-resolution remote-sensing information in the marine realm has allowed for a better appreciation of architectural elements associated with a variety of deep-water deposits, including MTDs. In this context, the three-dimensionality of MTD blocks has been described exhaustively in the subsurface, and now we have a better idea of the processes associated with their emplacement (Lee et al., 2004; Moscardelli et al., 2006; Alves, 2010; Dunlap et al., 2010; Jackson, 2011, 2012). Jackson (2011) documented the architecture of large MTD blocks that he called *megaclasts* in the Santos Basin, where the host MTDs were generated by slope failures off the Brazilian continental margin during the Tertiary (Modica and Brush, 2004). The Santos Basin Tertiary megaclasts are located in the distal part of a regional MTD that is 350 m thick and that covers a minimum area of 5000 km^2 (Jackson, 2011; see his figure 2). Individual Tertiary megaclasts can be 5 km long and 350 m thick and can cover 10 km^2 areas (Fig. 3). Sediment volume of individual megaclasts has been estimated at ~7 km^3 (Fig. 5). Tertiary megaclasts in the Santos Basin also feature a high degree of internal deformation that is manifested by the presence of abundant faults and folds that were generated during emplacement (Jackson, 2011) (Fig. 3). Smaller megablocks associated with the collapsing flanks of salt diapirs during the Cretaceous have also been documented within detached MTDs covering ~50 km^2 in the Santos Basin (Jackson, 2012; see his figures 4 and 6). These Cretaceous megaclasts can reach 50 m in thickness, 1.5 km in length, and can cover 1 km^2 areas (Fig. 5) (Jackson, 2012). The vertical and horizontal resolution of the 3-D seismic volume that was used to describe both Tertiary and Cretaceous megaclasts in the Santos Basin is 10 m and 12.5 m, respectively (Jackson, 2011, 2012). In other words, any internal elements, such as boulders or smaller blocks, <10 m thick and <12.5 m in plan view would be difficult to image using this seismic volume. However, note that these Tertiary and Cretaceous megaclasts most likely underwent some degree of disaggregation during transport, similar to that observed for MTD blocks in the Guandacol Formation in Argentina, where smaller boulders are the byproducts of megaclast disaggregation (Dykstra et al., 2011). Identification of MTD blocks or megaclasts in the subsurface is not exclusive to the Santos Basin, and many authors have documented their presence in other settings (Fig. 5). Alves (2010) documented the presence of similar Miocene megaclasts in the Espiritu Santo Basin in offshore Brazil (see his figures 1 and 2). Lee et al. (2004) (see their figure 4) and Dunlap et al. (2010) (see their figure 21) reported the presence of Cretaceous-age blocks that can reach 4 km^2 in area and 200 m in thickness in offshore Morocco. Moscardelli et al. (2006) showcased scour marks in the deep-water region of eastern offshore Trinidad that had been generated by the transport of big blocks during a debris-flow event. The evidence suggests that a wide range of boulder- to megaclast-size blocks is ubiquitous in terrestrial submarine MTDs.

ANALOGY BETWEEN VBF BLOCKS AND MTD MEGACLASTS AND BOULDERS

The origin of the VBF remains debatable, with some hypotheses suggesting that the genesis of this unit is linked to processes that took place in an ancient ocean in which most of the sediments had been transported and deposited as a suspended-sediment load (Kreslavsky and Head, 2002). Other researchers have suggested that the VBF is the result of frozen deposits of sediment-laden water that originated from giant outflow channels (Carr and

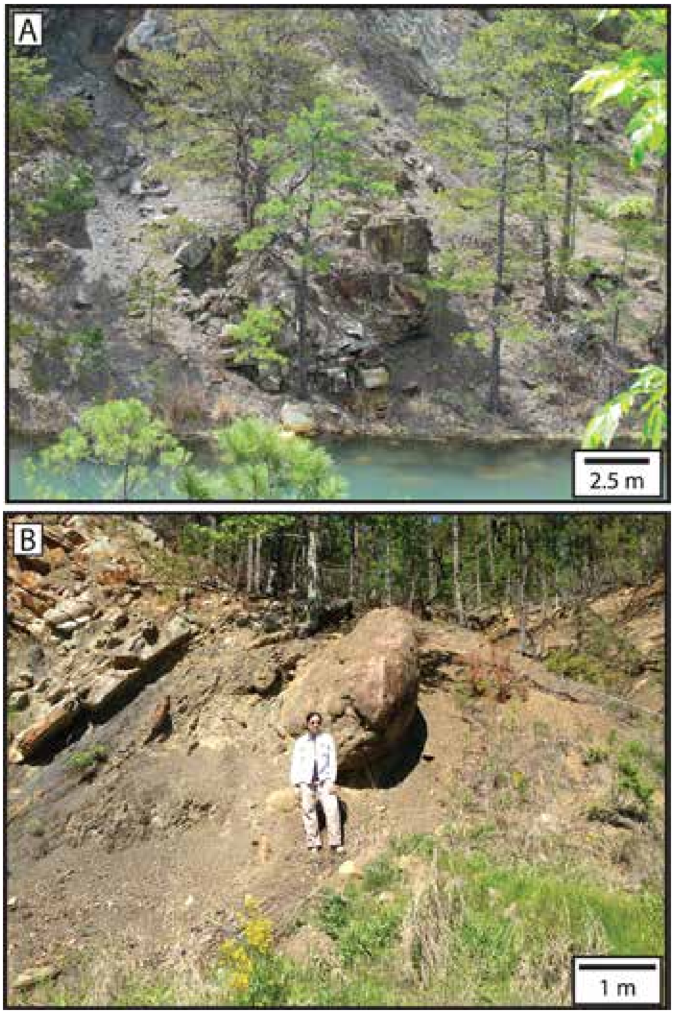

Figure 4. Megablocks of varying sizes embedded within mass-transport deposits of the Jackfork Group in Arkansas, USA. (A) DeGray Lake Spillway location. (B) Pinnacle State Park exposure. Image facilitated by Roger Slatt.

Head, 2003). HiRISE (high-resolution imaging science experiment) images over the northern plains of Mars have revealed the presence of boulders that form part of the VBF and that can range in size from 0.5 to 2 m in diameter (Fig. 2). McEwen et al. (2007) pointed out that the boulder distribution within the VBF is difficult to reconcile with the hypothesis that the unit consists primarily of a thick deposit of fine-grained materials that settled out of sediments suspended in an ancient martian ocean. However, recent advances in 3-D seismic-reflectivity–imaging techniques, drawn mainly from offshore oil and gas exploration activities around the world, have allowed us to uncover geomorphological complexities within deep-water environments that have changed our perception of how depositional processes operate in the marine realm. We have come to see that sedimentation processes in oceans are not exclusively dominated by suspended sediment load and that the spectrum of high-energy, dynamic processes operating in these deep-water environments is wide. Mass-transport events are one of the many processes that can generate deep-water deposits that can cover hundreds to thousands of square kilometers (Lee et al., 2004; Alves, 2010; Dunlap et al., 2010; Jackson, 2011, 2012; among many others). Terrestrial analogs clearly demonstrate that subaqueous MTDs can mobilize huge amounts of sediment into deep-water basins. One of the largest documented terrestrial MTDs on record, the Pleistocene Børnøja Fan Slide Complex, was described in the Barents Sea at water depths of 3,000 m (Hjelstuen et al., 2007). The Børnøja Fan Slide Complex remobilized 25,000 km^3 of glaciogenic sediments and covered a 120,000-km^2 area during the Northern Hemisphere Glaciation (Hjelstuen et al., 2007). Given these terrestrial analogies, it would be plausible that boulders contained within the VBF were transported to the northern plains of Mars as the result of catastrophic mass-wasting events associated with the debouchment of sediments from outflow channels during late Hesperian–early Amazonian time. The presence of boulders within the VBF does not present a conflict with a potential subaqueous origin for this unit, in which the water-sediment interface could have enhanced the capacity of the flow to erode and transport boulder-size rocks.

Alternative hypotheses have been offered to explain the emplacement mechanisms of blocks observed within the VBF. One of these suggests that VBF boulders were ejected as the product of meteorite impacts (Catling et al., 2011, 2012). Undoubtedly, meteorite impacts have the capacity to disrupt the targeted substratum, and some of the boulders observed on the northern plains of Mars could have been emplaced as the result of these processes. However, HiRISE imagery clearly shows impact-free boulder fields within the VBF that occupy hundreds of square kilometers (Fig. 2). This implies that a causal link between meteorite impacts and boulder occurrence is very unlikely. While the meteorite impact hypothesis can certainly explain the occurrence of some of the boulders observed on the northern plains of Mars, especially those that occur in close proximity to impact craters, it does not provide a comprehensive mechanism to understand the wide distribution of boulders in these regions. It has also been argued that periglacial activity associated with recent ice deposition might be involved in the formation of patterned grounds containing boulders in the northern plains of Mars (Milliken et al., 2003; Head et al., 2003; Levy et al., 2010). However, the VBF is an older unit of late Hesperian–early Amazonian age, and a variety of geomorphological patterns contained within this unit can be better explained by establishing a marine origin (Cooke et al., 2011; Moscardelli and Wood, 2011; Moscardelli et al., 2012; Oehler and Allen, 2012; Allen et al., 2013). The link between boulders in the northern plains of Mars and submarine processes is supported not only by a direct analogy with what could represent their terrestrial counterparts (megablocks) but also by placing their occurrence into a broader context that is conducive to supporting a marine origin (Parker et al., 1989, 1993; Cooke et al., 2011; Moscardelli and Wood, 2011; Moscardelli et al., 2012; Allen et al., 2013).

DISCUSSION

Discussion of the hypothetical existence of a late Hesperian–early Amazonian ocean on Mars should not revolve exclusively around an acceptance or rejection of a single line of evidence (e.g., the paleoshoreline argument). Search for additional evidence to support the idea of a hypothetically ancient ocean on the northern plains of Mars should also expand to areas presumably covered by

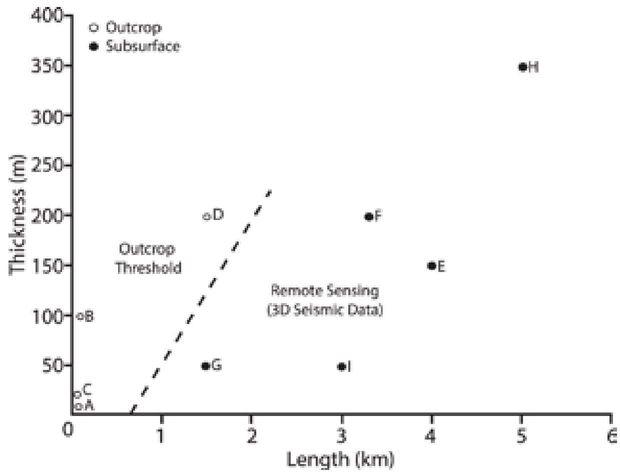

Figure 5. Relationship between length and thickness of reported deep-water megablocks from both outcrop and subsurface locations. A—Member A1, Ablation Point Fm. (Antarctica); B—Member A2, Ablation Point Fm. (Antarctica); C—Member B6, Ablation Point Fm. (Antarctica); D—Himalia Ridge (Antarctica); E—Tertiary Tejas A Fm., Tarfaya-Agadir Basin (Morocco); F—Cretaceous MTD, Safi Haute Mer (Morocco); G—Cretaceous MTD, Santos Basin (Brazil); H—Tertiary attached MTD, Santos Basin (Brazil); I—Miocene MTD, Espiritu Santo Basin (Brazil). Data collected from Macdonald (1993), Lee et al. (2004), Alves (2010), Dunlap et al. (2010), and Jackson (2011, 2012). MTD—detached submarine mass-transport deposit.

water (Carr and Head, 2003). In this context, documentation of kilometer-scale blocks and boulders in a variety of terrestrial, deep-water deposits suggests that the occurrence of boulder-size rocks in the VBF does not preclude a subaqueous origin for this unit. Therefore, portions of the VBF may very well have been deposited as part of underwater MTDs. The meter-scale boulders that have been revealed by HiRISE images could have been transported by mass-wasting events associated with the formation of outflow channels and deposited in Oceanus Borealis (Baker et al., 1991). The presence of boulders within the VBF is not the only analogy within the rim of the martian northern plains that supports the existence of an ancient ocean. A multitude of recently documented terrestrial analogs also support this marine hypothesis (Allen et al., 2013; Cooke et al., 2011; Moscardelli and Wood, 2011; Moscardelli et al., 2012; Oehler and Allen, 2012) (Fig. 1). Major arguments against the paleoshoreline interpretation of Parker et al. (1989, 1993) highlight the significant variations in elevation associated with these boundaries. These arguments are valid in a scenario in which the absence of tectonism and associated structural deformation could not justify postdepositional deformation of the alleged paleoshorelines. However, the recent discovery of potentially large-scale and narrow strike-slip faults in the Valles Marineris region has raised questions about the tectonic quiescence of Mars (Yin, 2012). These findings suggest that the Tharsis Rise experienced two major episodes of tectonism during late Hesperian and late Amazonian times (Yin, 2012). If there had been active tectonism on Mars, then these processes could have deformed the paleoshorelines and caused the observed changes in elevation, circumventing earlier arguments against previous interpretations (Parker et al., 1989, 1993). In addition, alteration of the alleged paleoshorelines by the action of true polar wander has also been suggested as an alternative mechanism of deformation (Perron et al., 2007).

Evidence supporting the existence of Oceanus Borealis (Baker et al., 1991) goes beyond the identification of terrestrial, deep-water geomorphological analogies. Data from the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) also support a subaqueous origin of the VBF by reporting a low, dielectric constant associated with these deposits (Mouginot et al., 2012). However, data from the shallow subsurface radar (SHARAD) suggest that the VBF presents far greater heterogeneities than those reported by MARSIS. These heterogeneities are expressed by the presence of terrains that have a closer affinity with low-loss basaltic flows or ashes in areas such as Amazonis Planitia (Boisson et al., 2011). The potential presence of basaltic-like terrains on the northern plains of Mars is considered by some as an impediment to support a late Hesperian–early Amazonian oceanic hypothesis (Catling et al., 2012); however, it has also been suggested that these terrains are in fact weathered basalts that degraded under marine conditions (Wyatt and McSween, 2002). These apparent contradicting views reflect the complexities associated with the acquisition, processing, and proper interpretation of radar data on Mars. The ground-penetrating radar (GPR) that will be launched in 2018 as part of the European Space Agency's *ExoMars* rover will include an instrument capable of operating over a much broader and higher-frequency range that will hopefully provide additional data to complement the observations already made by MARSIS and SHARAD.

Baker et al. (2000) also hypothesized that the Olympus Mons aureole deposits are subaqueous MTDs similar to those described in the Hawaiian Islands (Moore et al., 1989). This interpretation would imply that the total volume of water occupying the northern plains of Mars would have been equivalent to 3.5×10^8 km^3 (Carr and Head, 2003). Under this scenario, the paleoshorelines of Parker et al. (1989, 1993) were most likely submerged, raising the question of the validity of a coastline interpretation for these lineations. Carr and Head (2003) also pointed out the difficulty in identifying features that could exclusively indicate paleoshorelines in the northern plains, because these zones overlap with layering in bedrock and mass wasting. If the paleoshorelines of Parker et al. (1989, 1993) had been submerged, then the break in slope (martian dichotomy) could be better explained by the presence of a paleoshelf-break where mass-wasting processes would have been prevalent. The suggestion that teardrop-shaped islands might have formed in a continental-slope setting (Moscardelli and Wood, 2011) supports the paleoshelf-break hypothesis to explain the martian dichotomy, indicating that we might need to raise estimates of the volume of water that once occupied the northern plains of Mars (Newton, 2011). The potential existence of a martian ocean will be a topic of debate for many years to come. In an increasingly data-rich environment, where remote information from a multitude of martian missions and instruments is constantly pouring into the planetary geology community, we need to ensure that proper data integration with a wide range of disciplines is achieved. Knowledge derived from seismic geomorphological analysis of deep-water systems on Earth has proven to be useful for the establishment of new terrestrial analogies that support the existence of a martian ocean.

Verification of this hypothesis will only arrive with direct access to uncontaminated samples.

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GSA Position Statements

GSA Council approved three new position statements in 2013 and revisions to two existing statements. Full versions are available online at **www.geosociety.org/positions/.** GSA members are encouraged to use the statements as geoscience communication tools when interacting with policy makers, students, colleagues, and the general public.

NEW STATEMENTS

Critical Mineral Resources

Mineral resources are essential to modern civilization, and a thorough understanding of their distribution, consequences of their use, and the potential effects of mineral supply disruption is important for sound public policy.

Managing U.S. Coastal Hazards

Storms, tsunamis, and rising sea levels threaten U.S. coastal communities and their economies. Much of the nation's existing coastal infrastructure must be adapted to expected future conditions or relocated. New coastal development and post-storm reconstruction should be planned, sited, and maintained with coastal geologic hazards clearly in mind.

Promoting Earth Science Literacy for Public Decision Making

GSA recognizes the critical need for citizens and policy makers to understand important aspects of the Earth system as they face issues related to natural resources, energy, natural hazards, and human impacts on the environment. GSA supports the active involvement of geoscientists and geoscience educators in helping to improve the knowledge and understanding of the geosciences among members of the general public in order to support informed decision making by Earth's citizens and communities. GSA and GSA members should contribute to education and outreach about fundamental concepts of earth science, issues related to long-term human sustainability on Earth (such as the use and availability of water, minerals, and energy resources), and socially prominent topics (such as climate change and natural hazards preparedness).

REVISED STATEMENTS

Climate Change

Decades of scientific research have shown that climate can change from both natural and anthropogenic causes. GSA concurs with assessments by the National Academies of Science (2005), the National Research Council (2011), and the Intergovernmental Panel on Climate Change (IPCC, 2007) that global climate has warmed and that human activities (mainly greenhouse-gas emissions) account for most of the warming since the middle 1900s. If current trends continue, the projected increase in global temperature by the end of the twenty-first century will result in significant impacts on humans and other species. Addressing the challenges posed by climate change will require a combination of adaptation to the changes that are likely to occur and global reductions of CO_2 emissions from anthropogenic sources.

Diversity in the Geosciences Community

GSA affirms the value of diverse scientific ideas, and the connection between diverse scientific ideas and a diverse group of contributors of those ideas, including those who comment and criticize.

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FIELD CAMP SCHOLAR AWARD

Who should apply? Undergraduate students

Deadline to apply: 18 April

This year's field award will provide US$2,000 each to 17 undergraduate students so they can attend the summer field camp of their choice. These scholarships are based on diversity, economic/financial need, and merit.

BIGHORN BASIN FIELD AWARD

Who should apply? Undergraduate and graduate students and faculty

Deadline to apply: 18 April

Camp dates: 4–10 August

This award covers all costs for selected students and faculty to take part in a week-long field seminar in the Bighorn Basin of north-central Wyoming that emphasizes multidisciplinary integrated basin analysis.

FIELD CAMP EXCELLENCE AWARD

Who should apply? Anyone, but the award must be used toward field camp operations

Deadline to apply: 18 April

One field camp instructor/director will receive an award of US$10,000 to assist with his or her summer field season. This award will be based on safety awareness, diversity, and technical excellence.

Questions? Contact Jennifer Nocerino, jnocerino@geosociety.org, 1-303-357-1036.

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Call for Award Nominations

GEOPHYSICS DIVISION GEORGE P. WOOLLARD AWARD

Nominations due 15 February

Submit online at http://bit.ly/1djhX1s. Nominations should include a description of the nominee's specific contributions and their scientific impact.

This award recognizes outstanding contributions to geology through the application of the principles and techniques of geophysics. A highlight of the presentation is the honorary George P. Woollard Technical Lecture by the recipient before the award ceremony. Award funds are administered by the GSA Foundation.

SEDIMENTARY GEOLOGY DIVISION LAURENCE L. SLOSS AWARD FOR SEDIMENTARY GEOLOGY

Nominations due 20 February

Send (1) a cover letter describing the nominee's accomplishments in sedimentary geology and contributions to GSA; and (2) a curriculum vitae electronically to Linda Kah, Sedimentary Geology Division, lckah@utk.edu.

This annual award recognizes a sedimentary geologist whose lifetime achievements best exemplify those of Larry Sloss—i.e., achievements that contribute widely to the field of sedimentary geology and service to GSA. Monies for the award are derived from the annual interest income of the Laurence L. Sloss Award for Sedimentary Geology Fund, administered by the GSA Foundation.

COAL GEOLOGY DIVISION GILBERT H. CADY AWARD

Nominations due 28 February

Send three copies each of the following: (1) name, office or title, and affiliation of the nominee; (2) date and place of birth; (3) education, degree(s), honors, and awards; (4) major events in his or her professional career; and (5) a brief bibliography noting outstanding achievements and accomplishments that warrant nomination to Jack C. Pashin, Energy Investigations Program, Geological Survey of Alabama, P.O. Box 869999, Tuscaloosa, AL 35486-6999; jpashin@gsa.state.al.us.

This award recognizes outstanding contributions in the field of coal geology within and outside North America. Monies for the award are derived from the annual interest income of the Gilbert H. Cady Memorial Fund, administered by the GSA Foundation.

ENVIRONMENTAL AND ENGINEERING GEOLOGY DIVISION RICHARD H. JAHNS DISTINGUISHED LECTURER

Nominations due 28 February

Send nominations to Dennis Staley, USGS, Box 25046, MS 966, Denver, CO, 80225, USA; dstaley@usgs.gov.

This lectureship was established in 1988 by GSA's E&EG Division and the Association of Environmental & Engineering Geologists to commemorate Jahns and to promote student awareness of engineering geology through an annual series of lectures at academic institutions. The lectureship recognizes an individual who through research or practice has made outstanding contributions to the advancement of environmental and/or engineering geology. The awardee will speak on topics of earth processes and the consequences of human interaction with these processes, or the application of geology to environmental and/or engineering works. Award funds are administered by the GSA Foundation.

JOHN C. FRYE ENVIRONMENTAL GEOLOGY AWARD

Nomination deadline: 31 March

This US$1,000 cash award, which is managed by the GSA Foundation, 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, and Recognition, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA; awards@geosociety.org.

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

Nominations due 2 April

Send (1) a statement of the significance of the nominee's research; (2) a curriculum vitae; (3) letters of support; and (4) copies of no more than five of the nominee's most significant publications related to desert research to David P. Dethier, ddethier@williams.edu. Please submit electronically unless hard-copy previously approved.

This award recognizes excellence in desert geomorphology research worldwide. Although the award primarily recognizes achievement in desert research, the funds that accompany it may be used for further research. Any scientist from any country may be nominated, and nominators and nominees do not need to be GSA Members. Monies for the award are derived from the annual interest income of the Farouk El-Baz Fund, administered by the GSA Foundation.

2013 OEST Awards

The National Association of Geoscience Teachers (NAGT) has announced the 2013 Outstanding Earth Science Teacher (OEST) Awards. This annual award recognizes excellence in earth-science teaching at the pre-college level. GSA awards the section recipients US$500 in travel money to attend a GSA meeting, US$500 for classroom supplies, and complimentary membership in GSA for three years. State winners receive a complimentary one-year GSA membership.

SECTION WINNERS

Eastern
Russell H. Kohrs
Broadway High School
Broadway, Virginia, USA

Pacific Northwest
Helen Farr
Millicoma Intermediate School
Coos Bay, Oregon, USA

New England
Erica Wallstrom
Rutland High School
Rutland, Vermont, USA

Central
Mary Lestina
Iowa City City High School
Iowa City, Iowa, USA

Southeastern
Olivia Boykin
Woodland Heights Elementary
Spartanburg, South Carolina, USA

Southwest
Cheryl L.B. Manning
Evergreen High School
Evergreen, Colorado, USA

North Central
Rod Benson
Helena High School
Helena, Montana, USA

Midcontinent
Kathy Rusert
Acorn High School
Mena, Arkansas, USA

Far Western
Herman Hilkey
San Jacinto High School
San Jacinto, California, USA

Texas
Gary Poole
The Girls' School of Austin
Austin, Texas, USA

STATE WINNERS

Texas
Katie Wagner
Kinkaid School
Houston, Texas, USA

Alaska
Jonathan Smith
Juneau-Douglas High School
Juneau, Alaska, USA

New York
Michael Wing
Hommocks Middle School
Larchmont, New York, USA

New Jersey
Steven Carson
John Witherspoon Middle School
Princeton, New Jersey, USA

Alabama
Alison Starr
Auburn High School
Auburn, Alabama, USA

Louisiana
Lacey Hoosier
Buckeye High School
Deville, Louisiana, USA

Arizona
Jeremy Williams
Desert Vista High School
Phoenix, Arizona, USA

North Carolina
Mary Catherine Mills
Southern Guilford High School
Greensboro, North Carolina, USA

Georgia
Nancy E. Adgate
Dutchtown High School
Hampton, Georgia, USA

The National Association
of Geoscience Teachers

Penrose Conference Announcement

Extensional Reactivation of Thrust Faults, Coseismic Surface Rupture, and Crustal Evolution in the Eastern Basin and Range Transition Zone

4–9 August 2014
Evanston, Wyoming, USA

Application deadline: 4 April

CONVENERS

Co-Chair ***Michael W. West,*** *Michael W. West & Associates, Inc., mwest@m-west-assoc.com*

Co-Chair ***Stephen A. Sonnenberg,*** *Colorado School of Mines, ssonnenb@mines.edu*

Paul M. Santi, *Colorado School of Mines, psanti@mines.edu*

Tarka Wilcox, *Michael W. West & Associates, Inc., twilcox@m-west-assoc.com*

Rare geologic terranes exist in intraplate areas of the North American continent that illuminate nascent crustal-scale tectonic processes, fault nucleation/evolution, interaction of geologic structures in changing stress fields, tectonic effects on topography and fluvial systems, and issues in seismic hazard/risk assessment. These terranes, if recognized, are ideally suited to multidisciplinary research, leading to greater understanding of crustal evolution from the crust-mantle interface to surface geomorphology. Conference participants will have the opportunity to examine and assess active crustal deformation in an area encompassing the Laramide Uinta Mountains uplift; the Absaroka and Darby/Hogsback thrust plates of the Sevier orogenic belt (Wyoming and Utah); the late Holocene Bear River fault zone (BRFZ); and the transition between the contemporary margin of the Basin and Range province and the adjacent Laramide Green River Basin (Figs. 1A–1D and 2). The Bear River fault zone exhibits the largest reported paleo-displacements in the Basin and Range province, indicating the terrane encompassing the BRFZ and extensionally reactivated thrust faults is among the most tectonically active in the transition zone.

Specific conference topics include (1) crust/mantle interaction in the eastern Basin and Range transition zone, 100+ km east of the Wasatch Front; (2) stress, strain, and rheology at the intersection of the Uinta Mountains, Sevier thrust belt, Green River Basin, and active Basin and Range extension; (3) kinematics and evolution of crustal-scale structures from compression through contemporary extension; (4) relation of late Holocene co-seismic fault ruptures to preexisting Sevier and Laramide thrust faults; (5) refinement of seismogenic fault histories and surface-rupture parameters; (6) seismogenesis and hazards related to surface rupture along low-angle faults; (7) tectonic effects on glacial and fluvial geomorphic systems; (8) glacial loading/unloading effects on fault surface-rupture; (9) geophysical imaging of structures from the near subsurface to the crust/mantle interface; (10) applications of geodesy, LiDAR, and INSAR to crustal deformation and comparison to paleoseismological methods; and (11) relation of hydrocarbon occurrence to active, extensional tectonism.

The conference area provides an important, largely untapped field laboratory in which to study the interaction of contemporary extensional tectonic processes with older structures, reflected in modern topography and geomorphology. We suggest that this part of the eastern Basin and Range transition zone may be a "Rosetta" terrane, highlighting tectonic interactions in a complex geologic setting. Late-onset extension illuminates subsurface structural relations, reflected in surface deformation, which would likely not be recognized either in unextended terranes or, conversely, in highly extended terranes where initial structural relations may become indecipherable. Moreover, the juxtaposition of active extension against the relatively stable geomorphology of the Green River basin provides an opportunity to assess the timing and effects of late-onset extension on landscape development. We expect that the conference will yield new insights related to the region's crustal evolution with applications transferable to other terranes affected by changing stress fields. Conference participants will be tasked with determining if the project area should be designated as a prototype "national field laboratory" to encourage focused research on crustal-scale tectonic processes. A proposal to NSF to support the conference under the EarthScope program is pending.

The conference, including focused technical presentations, field trips, and workshop, will be held in Evanston, Wyoming, USA, at the historic Union Pacific Railroad Roundhouse Conference Center. As currently planned, the conference will encompass five days:

- Day 1—Focused technical presentations introducing the conference area;
- Day 2—Field trip to the Bear River fault zone from southeast of Evanston to the north flank of the Uinta Mountains;
- Day 3—Field trip to view evidence for extensional reactivation of the Absaroka and Darby/Hogsback thrust faults at the contemporary margin of the Basin and Range province, 130 km east of the Wasatch Front;
- Day 4—Focused technical recommendations and workshop to discuss conference topics and to identify priorities for future research;
- Day 5—Summary session.

Figure 1. (A) Low-sun angle aerial view of the Big Burn scarp (dotted yellow line at midpoint of scarp) at the south end of the Bear River fault zone (BRFZ). The scarp is 15+ m high in glacial tills and outwash. (B) View of trench wall excavated across the Lester Ranch scarp, BRFZ, showing colluvial wedges, surface soil, and two buried organic soils delineating surface faulting events at about 4.6 ka and 2.2 ka. (C) Low sun angle views to the south along Holocene fault scarps, BRFZ, showing tilting of flood plain. The active stream channel, due to back-tilting, is eroding the scarp. The former channel is preserved on upthrown block. (D) View of block faulting, looking south, along the west side of the Bigelow Bench outwash surface. Note displacement of the outwash surface, eastward back-tilting, and possible graben development.

ATTENDEES AND ESTIMATED COST

Participants are responsible for their own travel arrangements and should plan to arrive in Evanston by 5 p.m. on the afternoon of Monday, 4 August 2014. Transportation will be arranged from the Salt Lake City airport to Evanston by shuttle and/or a possible field trip. An “icebreaker,” the first scheduled conference dinner, and a brief introduction to the conference program and field trips is planned for Monday evening.

The registration fee will cover airport transfers, hotel lodging for five nights (4–8 August), meals, field trips, guidebooks, and transportation while in Evanston. The exact registration fee, to be determined, is expected to be less than US$1,000. Financial assistance may be available for conference speakers and field trip leaders. Students are encouraged to attend, and financial assistance (to be determined) will be available for student support.

REGISTRATION APPLICATIONS

Registration deadline: 4 April

If you are interested in attending, please send an e-mail to Michael W. West, mwest@m-west-assoc.com, providing a brief statement of your research interests and the relevance of those interests to the focus of the conference. If you would like to present a technical paper on a topic relevant to the conference, please provide the proposed title and an informal abstract. A copy of the Penrose Conference proposal (PDF format), containing details on the planned program, conference topics, and field trips is available on request. Presentations should focus specifically on the eastern Basin and Range transition zone or analogs that illuminate conference topics.

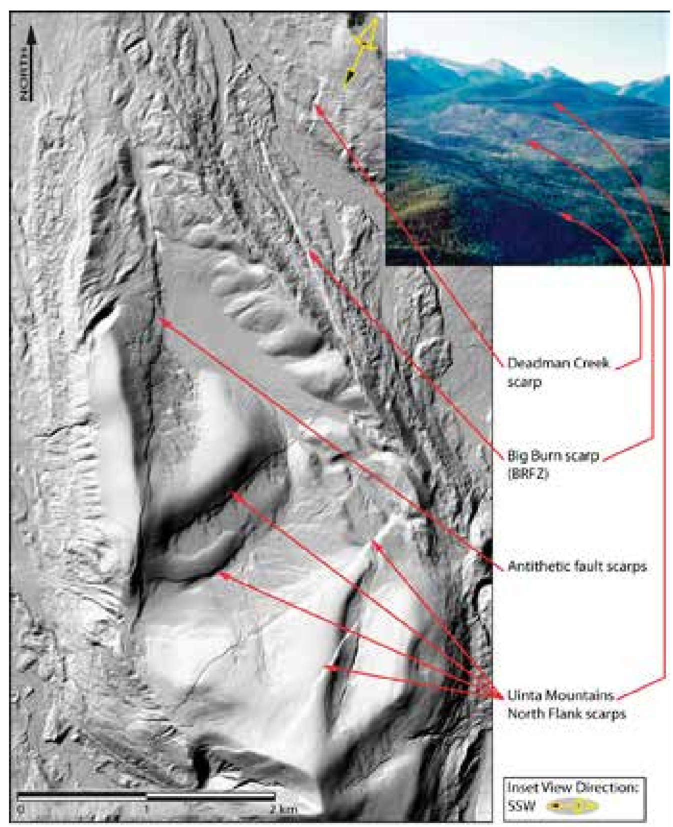


Figure 2. LiDAR image (evening illumination) of the south end of the BRFZ at the intersection with the Uinta Mountains uplift, showing the Big Burn scarp, antithetic scarps, and scarps sub-paralleling the north flank of the Uinta Mountains. Inset: Low-sun angle aerial view, looking S-SW, of the intersection of the Big Burn scarp, BRFZ, with the north flank of the Uinta Mountains.

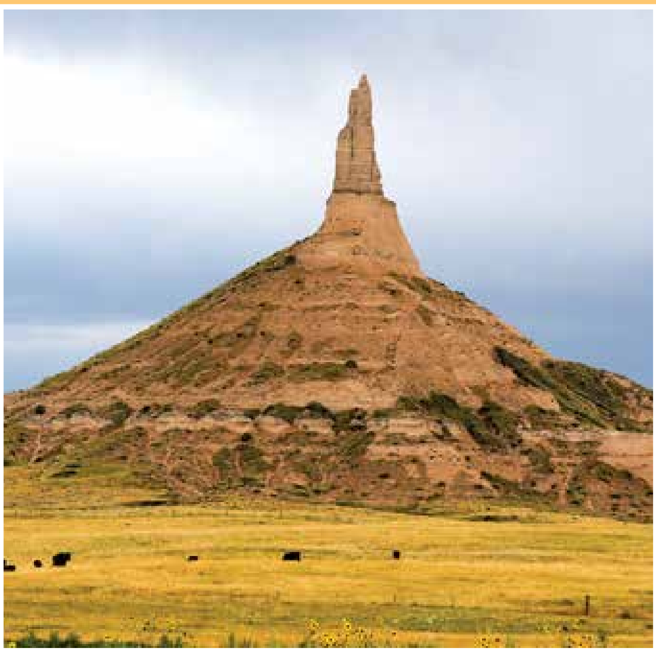
Second Announcement

NORTH-CENTRAL SECTION

48th Annual Meeting, North-Central Section, GSA
Lincoln, Nebraska, USA

24–25 April 2014

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



Chimney Rock National Historic Site, Morrill County, Nebraska.
Photo by Allen Stutheit; used with permission of Wikimedia Commons.

Explore Midcontinental Geology and Walk with Mammoths in Nebraska's Beautiful Capital City!

LOCATION

The University of Nebraska–Lincoln (UN-L) Conservation and Survey Division, School of Natural Resources, Dept. of Earth and Atmospheric Sciences, and the University of Nebraska State Museum are hosting the 2014 North-Central Section Meeting at the Cornhusker Marriott Hotel in Lincoln, Nebraska, USA. Lincoln is located near the boundary between the Great Plains and glaciated Central Lowlands. The Nebraska Sand Hills—the largest dunefield in the Western Hemisphere—as well as the thickest loess sequence in North America are within a half-day's drive. The Missouri River, which drains a significant portion of the North American continent, and the Platte River, which is a classic braided stream, lie within 60 km. Rock strata from Upper Pennsylvanian to Upper Neogene in age are exposed in the eastern half of Nebraska, including the type sections of the Cretaceous Niobrara and the Dakota Formations. Limestone, clay, and sand and gravel are produced in the vicinity, and interest in the development of the nearby Elk Creek carbonatite is escalating. Nebraska is one of the most important regions in the world for the collection and study of Cenozoic mammals, and the University of Nebraska State Museum is one of the premier repositories for such fossils. The eastern edge of the High Plains Aquifer lies just north of Lincoln.

REGISTRATION

Early registration deadline: 24 March
Cancellation deadline: 31 March
REGISTRATION FEES (all fees are in U.S. dollars)

	Early		Standard	
	Full Mtg.	One Day	Full Mtg.	One Day
Professional Member	$150	$100	$170	$110
Professional Member 70+	$90	$70	$110	$70
Professional Nonmember	$175	$120	$215	$135
Student Member	$50	$35	$65	$45
Student Nonmember	$65	$45	$85	$60
K–12 Professional	$45	$35	$45	$45
Guest or Spouse	$35	$35	$45	$45
Field Trip or Workshop only	$35	n/a	$45	n/a

ACCOMODATIONS

A block of rooms has been reserved at The Cornhusker, A Marriott Hotel, 333 S 13th Street, Lincoln, NE 68508, USA, at US$104 + 16.48% hotel tax per night. Please call The Cornhusker at +1-866-706-7706 and request a reservation under "The Geological Society of America Group Rate."

FIELD TRIPS

GSA invites you to join your colleagues on one or more of the following field trips. Trip fees include transportation during the trip as well as a trip guide. All trips begin and end at the Cornhusker Marriott Hotel unless otherwise indicated. Check the meeting website for details.

1. **Ashfall Fossil Beds State Historical Park, Orchard/Royal, Nebraska.** Sat., 26 April. Cost: US$60.
   Nearly 12 million years ago, hundreds of rhinos, three-toed horses, saber-toothed "deer." camels, and other animals died and were buried around a watering hole. These exceptionally well-preserved skeletons lay undisturbed in a blanket of volcanic ash, which originated from a Yellowstone supervolcano, until the 1970s, when scientific excavation of the fossilized remains began. This snapshot in time captures the animals' death poses after their lungs filled with ash and they suffocated over a period of weeks. This one-day trip will visit the lagerstätten at Ashfall Fossil Beds, a National Natural Landmark located three hours from Lincoln. Participants will take a guided tour of the 17,500-square-foot "Rhino Barn," observe fifty skeletons preserved in three-dimensions, explore exhibits throughout the facility, and visit the gift shop. The group will stop for lunch at a nearby restaurant (participants

will be responsible for expenses). More information about the park can be found at www.ashfall.unl.edu.

2. **Pleistocene Geology and Classic Type Sections along the Missouri River Valley.** Sat., 26 April. Cost: US$95.

   We will visit quarries along the east side of the Missouri River Valley (MRV) with spectacular exposures of the three widespread loess sheets in the Midwestern U.S.: the Peoria Loess, Pisgah Formation, and Loveland Silt. These stops include the type sections of the Pisgah and Loveland, along with the type location of classical Nebraskan till. Exposures will be paired with cores taken from locations farther from the MRV to display changes in thickness, morphology, and paleosol development with respect to the valley, which was a major source of loess. The cores will also be used to illustrate the entire sequence of six pre-Illinoian tills in this region, along with evidence pertaining to the timing and origin of the MRV in its present location between Iowa and Nebraska.

3. **Building and Ornamental Stones in the Nebraska State Capital Building.** Sat., 26 April. Cost: US$18.

   This field trip will examine the building and decorative stones used for the Nebraska capitol, a stunning Art Deco structure located in the heart of Lincoln, which includes outstanding examples of various stones quarried in the United States and Europe. This field trip also provides an overview of the geologic setting and paleontological iconography of the capitol. This trip is suitable for guests as well as geologists.

4. **Quaternary Landforms and History of the Nebraska Sand Hills**. Sat.–Sun., 26–27 April. Cost: US$155. Minimum of 10 people.

   This field trip will explore the geology and ecology of the Nebraska Sand Hills—a dunefield that occupies 50,000 km^2 in the Central Great Plains. Although the landscape is currently stabilized by prairie vegetation, optically stimulated luminescence dating of dune deposits indicates widespread mobility multiple times in the Holocene, with the latest event dating to 800–1000 years ago. Samples recovered during coring into large dunes have yielded ages that cluster at about 15,000–17,000 years, but the dunefield was clearly active long before that. The eastern Sand Hills are dominated by linear bedforms that are 10–15 m high and oriented NW-SE. Barchanoid ridges over 100 m high with E-W oriented crests are widespread in the central part of the dunefield. Lakes and marshes are widespread today in interdune areas. Lake muds, buried peat beds, bison tracks, and gopher burrows provide glimpses of ancient ecosystems.

OPPORTUNITIES FOR STUDENTS

Mentor Luncheons

Cosponsored by the GSA Foundation. Students will have the opportunity to discuss career prospects and challenges with professional geoscientists over a FREE lunch. See www.geosociety.org/mentors/ for more information.

Roy J. Shlemon Mentor Program in Applied Geoscience: Thurs., 24 April.

Mann Mentors in Applied Hydrogeology Program: Fri., 25 April.

GSA Geoscience Career Program Workshop

Are you about to embark on a job search? 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 Workshop is designed to help you begin this process. We will discuss cover letters, CVs/résumés, job-hunting skills, and job-market statistics.

Student Awards

Awards will be given for the best student presentations. To be eligible, students must be lead authors and presenters, and should be capable of answering detailed questions about the research. These awards are sponsored by the North-Central Section of GSA.

GSA Mentor Programs at the 2014 Section Meetings

Plan now to attend a **Roy J. Shlemon Mentor Program in Applied Geoscience** and/or a **John Mann Mentor Program in Applied Hydrogeology** luncheon at your 2014 Section Meeting to receive career advice and chat one-on-one with practicing geoscientists. **FREE lunches** will be served! Check the Section Meetings website, **www.geosociety.org/mentors/sectionSched.htm,** for times and locations. A reminder will be included on all student badges at the onsite registration desk. Space is limited, so plan to arrive early: first come, first served. If you have questions or want to serve as a mentor, please contact Jennifer Nocerino at jnocerino@geosociety.org.

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

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

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

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

JOINT ROCKY MOUNTAIN & CORDILLERAN
Bozeman, Montana, USA
Shlemon luncheon: Mon., 19 May
Mann luncheon: Tues., 20 May

www.geosociety.org/Sections/meetings.htm

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
(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 13 April 2014. www.geosociety.org/aboutus/officers.htm

Dedicating America's GSSPs—International Geostandards

Stanley C. Finney, *Chair: International Commission on Stratigraphy*

A "golden spike" was placed on a cliff face in Lake Pueblo State Park, Colorado, USA, on Friday, 25 October 2013. It marks the stratigraphic level of the base of the Turonian Stage of the Cretaceous System (Cenomanian–Turonian boundary) in that stratigraphic section. This Global Stratotype Section and Point (GSSP) serve as the global reference for the base of the Turonian Stage and beginning of Turonian Age. It is one of 63 GSSPs that have been approved by the International Commission on Stratigraphy (ICS) and ratified by the International Union of Geological Sciences (IUGS). Thus, it is recognized as an international geostandard, and it serves as the definition of one of the 100 standard global stages that comprise the standard series and systems of the ICS International Chronostratigraphic Chart, the basis for the Geologic Time Scale.

Of the 63 GSSPs ratified, seven are in the United States and one is in Canada. The GSSP at Lake Pueblo was the first GSSP in the United States to be dedicated; the GSSP defining the base of the Ordovician System (Lower Ordovician Series and Tremadocian Stage) at Green Point, western Newfoundland, Canada, was dedicated in 2001. The ceremony on 25 October was organized by Brad Sagemen of Northwestern University and Darcy Mount, park ranger at Lake Pueblo State Park. The GSSP proposal by Jim Kennedy (Oxford University), Ireneusz Walaszczyk (University of Warsaw), and William Cobban (deceased, USGS–Denver) was approved by ICS and ratified by IUGS in 2003. The boundary level is placed in the Lake Pueblo section at the lowest occurrence of the ammonite *Waitnoceras coloradoense* within a stratigraphic interval that includes several other biostratigraphic and chemostratigraphic signals that facilitate global correlation as well as several bentonite beds that allow its numerical age to be correlated with considerable precision. In recent years, Brad Sagemen, Steve Myers, and Brad Singer of Wisconsin have been applying high-resolution radioisotopic and astronomical dating to Cretaceous strata of the Western Interior Basin, including the Lake Pueblo section.

A sizeable group of interested geologists and personnel of the state park attended the dedication. In attendance were Suzanne Mahlburg Kay, president of GSA; Roland Oberhänsli, Ian Lambert, and Dong Shuwen, president, secretary-general, and treasurer of IUGS, respectively; Stan Finney, chair of ICS; Malcolm Hart, chair of the ICS Subcommission on Cambrian Stratigraphy; and Ireneusz Walaszczyk, co-author of the GSSP proposal. Besides placement of the golden spike (Fig. 1), an informative education display, designed by Brad Sageman, was formally opened (Fig. 2).

The final steps in establishment of a GSSP as a global geostandard are publication of the approved proposal in *Episodes* (Kennedy et al., 2005, accessible from the table of GSSPs on the ICS website, www.stratigraphy.org) and placement of a plaque or marker on the GSSP. Educational displays designed for the public enhance the GSSP and serve to provide information on and respect for the GSSP as a global geostandard. The dedication ceremony helped the personnel of the state park understand the importance of their stewardship of the site, which must be

Figure 1. Golden spike marking the Global Stratotype Section and Point (GSSP) for the Turonian Stage at the base of bed 86 in the section at Lake Pueblo State Park, Colorado, USA.

Figure 2. Brad Sageman explaining the educational panel that he designed for the Turonian GSSP. Photo by Bob Kay.

Figure 3. Marker for the base of the Guadalupian Series and Roadian Stage installed by Shuzhong Shen and Charles Henderson, chair and past chair of the Permian Subcommission, respectively, with Superintendent Dennis Vasquez and Geologist Jonena Hearst of the Guadalupe Mountains National Park, USA.

protected and maintained and available for future study, and it served to recognize the important contributions of those who developed the successful GSSP proposal.

When most of the traditional chronostratigraphic units were established, boundaries were rarely defined, and a myriad of regional chronostratigraphic units subsequently created further complicated international communication. Thus, in 1968, the ICS was established with the objective of developing a single hierarchal set of global standard chronostratigraphic units at the ranks of stage, series, and systems with boundaries precisely defined by GSSPs. Ratified GSSPs result from collaboration by international teams of stratigraphers to reach consensus on the stratigraphic extent of a chronostratigraphic unit and to select a stratigraphic level and section at which to define its base. A GSSP proposal developed by a boundary-working group must be approved by the relevant ICS subcommission by a super-majority vote (>60%) following extensive discussion and deliberation. A proposal approved by a subcommission is then considered by the voting members of ICS (the three-person executive and the chairs of the 16 subcommissions). If they approve it by a super-majority vote, it is forwarded to the IUGS executive committee for ratification. GSSP proposals are evaluated on a long list of criteria, the most important of which is that the GSSP is defined within a stratigraphic interval that contains a multitude of varied stratigraphic signals that allow for reliable, high-resolution correlation across the widest possible range of paleogeographical and paleoecological settings. The evaluation criteria and several levels of review give validity to ratified GSSPs as international geostandards.

In the summer of 2013, markers were placed for the GSSPs of the three successive stages (Roadian, Wordian, and Capitanian) that comprise the Guadalupian Series (Middle Series) of the Permian System (Fig. 3), which are located in a single stratigraphic section in the Guadalupe Mountains National Park. The GSSP for the base of the Pennsylvanian Subsystem (Lower Pennsylvanian Series and Bashkirian Stage) is located in the Arrow Canyon Range of southern Nevada on land managed by the Bureau of Land Management. Its location in a Wilderness Area makes access difficult, yet plans are underway for installing a marker and possibly an educational panel in the near future. The GSSP for the Drumian Stage of the Cambrian System is located in the Drum Mountains of western Utah on land managed by the Bureau of Land Management. It presently lacks a marker, and so does the GSSP for the Katian Stage of the Upper Ordovician Series, which is located on private land on Black Knob Ridge, Atoka County, Oklahoma. Plans are underway for dedicating the Katian GSSP during a field excursion associated with the 12th International Symposium on the Ordovician System in 2015.

With 63 of the 100 GSSPs that define its systems, series, and stages, the ICS International Chronostratigraphic Chart is now widely recognized as an international standard, as so too are the GSSPs. Although most are on land managed by various agencies of the federal government, land managers have only recently become aware of them and their significance. However, they become enthusiastic supporters once they have learned of their significance, as they did during a workshop presentation on "America's Geologic Heritage," hosted in Denver by the U.S. National Committee for the IUGS and sponsored by GSA, AGI, the Colorado Geologic Survey, the U.S. National Park Service, and the U.S. Geological Survey.

The 63 ratified GSSPs are located in 20 countries in Europe, Asia, northern Africa, North America, and Australia. The subcommissions of the ICS have more than 350 voting members representing 40 countries. Over the 45-year span of its work, several hundred more people have been involved as voting and corresponding members. Their contributions to this endeavor have (1) generated a huge body of stratigraphic information for the entire geological column from hundreds of sections worldwide and from deep-sea and ice cores; (2) driven significant advances in biostratigraphy and the taxonomy, paleoecology, and paleogeography of index fossil groups on which it is based; (3) stimulated the development, testing, and refinement of more modern tools for stratigraphic correlation, including magnetostratigraphy, chemostratigraphy, and cyclostratigraphy with astronomical tuning of sedimentary cycles; and (4) encouraged the development of modern techniques in isotope geochronology by providing a well-defined chronostratigraphy in which to integrate radiometric dates.

REFERENCE CITED

Kennedy, W.J., Walaszczyk, I., and Cobban, W.A., 2005, The Global Boundary Stratotype Section and Point for the base of the Turonian Stage of the Cretaceous: Pueblo, Colorado, U.S.A.: Episodes, v. 28, no. 2, p. 93–104.

P. Geoffrey Feiss, GSA Foundation President

Diversity in the Geosciences Committee

ON TO THE FUTURE

I have previously described the On To the Future (OTF) project to bring 125 students from underrepresented groups to their first-ever GSA meeting. Now that the meeting in Denver is history, we can report that 125 young students did indeed attend their first annual meeting. They were an ethnically diverse group: African American, Asian, Hispanic/Latino, Native American/Alaskan, Native Hawaiian/Pacific Islander, and Middle Eastern. Half were first-generation college-goers, nine were veterans, and nine were persons with disabilities. Many were attending or had attended two-year colleges. Also among the group were non-traditional students. Not your median GSA attendee.

This diversity was powerfully brought home on Saturday night (26 Oct.) when the OTF students gathered for an orientation. The room looked like America, not some GSA meeting of the 1950s. At the Saturday assembly, students heard powerful and resonating words from Francisca Oboh-Ikuenobe, chair of GSA's Diversity in the Geosciences Committee, and Wes Ward, a former chair of that committee and a member of the GSA Foundation Board of Trustees.

I confess to being deeply moved by what the hard work of so many has wrought.

Launching OTF was a grassroots endeavor at every step. Participants were "recruited" through conversations with GSA campus representatives or members. Numerous GSA staff and members rallied to get the word out and to create the online application process. The Diversity in the Geosciences Committee selected OTF participants and awarded travel grants and waivers of registration fees. The committee also participated in the creation and delivery of a multi-day program with guidance and assistance from GSA Education and Outreach staff.

Critically, financial support from many sources enabled us to exceed our initial fundraising goal of US$50,000—total funding for the 2013 meeting came to US$90,652. "I'm pleased GSA is doing something like this" was a common refrain among contributing members who already supported GSA or were making their first gift. Corporate sponsors and GSA Sections, Divisions, and Associated Societies numbered among OTF's supporters.

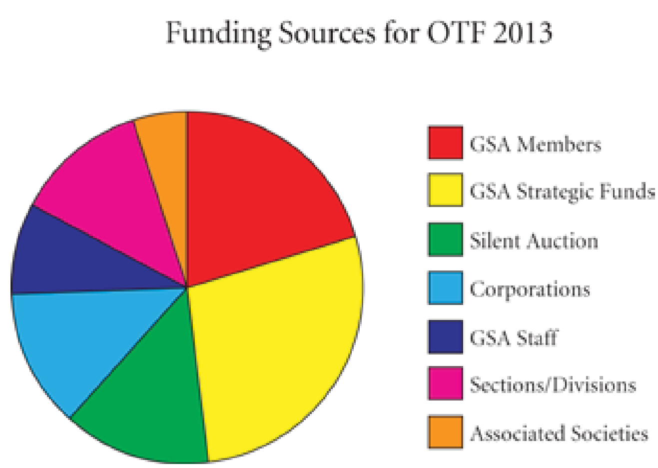
Funding Sources for OTF 2013

GSA Members: US$18,605
GSA Strategic Funds: US$25,000
Silent Auction: US$12,500
Corporations: US$11,500
GSA Staff: US$7,672
GSA Sections and Divisions: US$11,000
Associated Societies: US$4,375

The work is not complete. To impact the diversity of the geoscience workforce pool, this project must continue to bring underrepresented students to GSA meetings in the future—to give them a strong sense of the vibrancy of our science, to help them realize that there is a place for them in the geoscience workforce of the future, and to simply welcome them to our scientific community.

With your support, OTF will thrive in the future. Reaching our 2014 fundraising goal of US$70,000 will enable GSA to deliver a second, robust OTF program at the 2014 Annual Meeting in Vancouver, Canada.

Please join this effort to provide a seminal meeting experience for an inspiring and essential cohort of young geoscientists!



OTF Student Comments:

“Thank you sooo much for the OTF program. The experience was indescribable. Without the OTF financial support I would not have been able to attend the conference. I had the opportunity to learn and meet so many interesting professionals and students. Thanks to GSA for everything!”

“OTF gave me an opportunity among the best learning and networking occasions I have had. The Pardee symposium lectures about spirit of exploration inspired me a lot because I know what adventures and answers await me after the hard work. It was great meeting students and getting advice and different perspectives. The diversity reception and Women in Geology meeting assured me I won’t be alone and there are people like me who are more than willing to help me.”

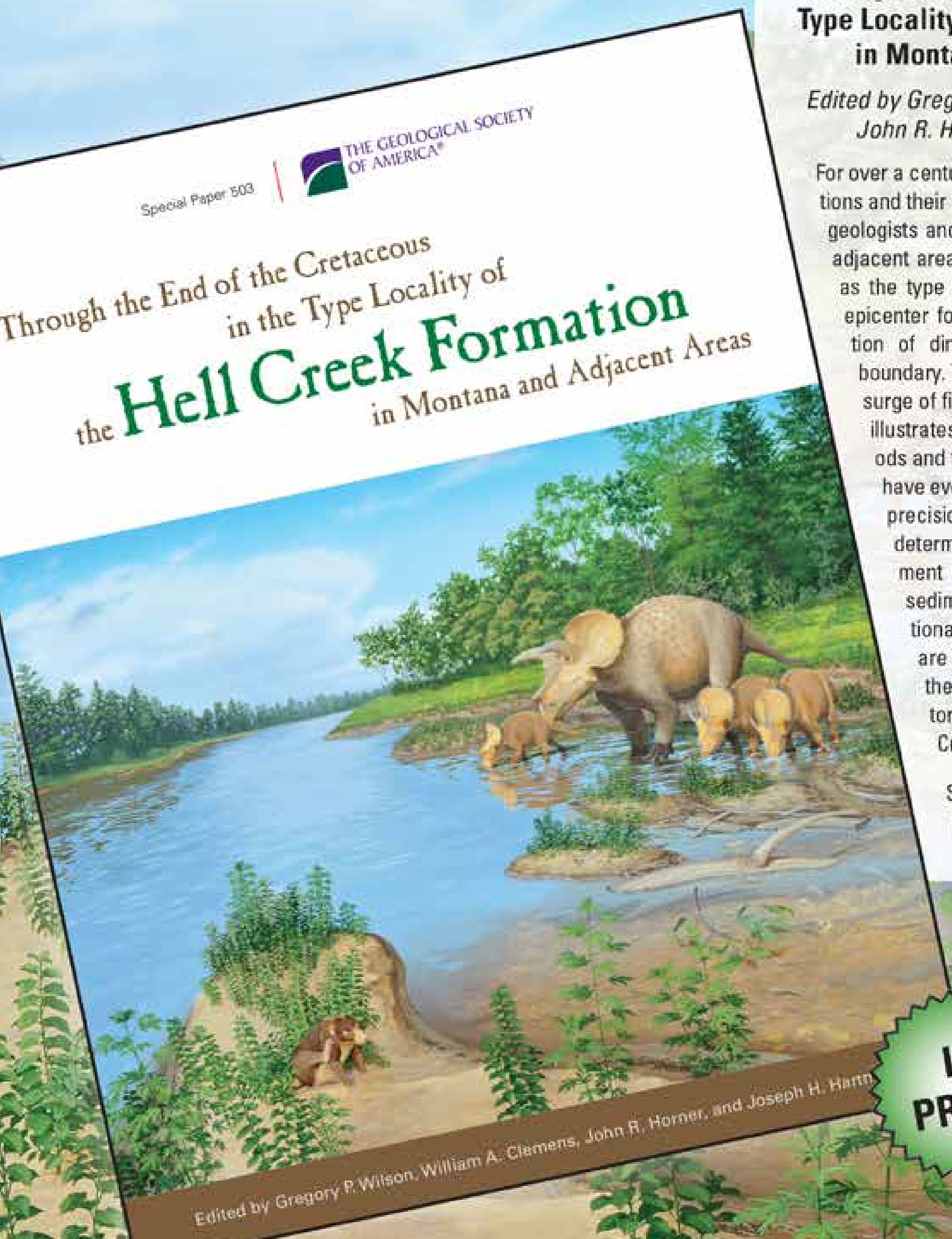
Student responses when asked

“Has your attendance at this meeting helped you make a better-informed decision about a career?”:

- “Yes! It exposed me to jobs and paths I had never knew about! Being from an inner city, there is very little exposure to geosciences.”
- “It helped show where my education is taking me and that I am making the right career choice.”
- “I’ve learned a little more about the industry. There is so much I can do with my degree. I think I know what I’d like to do with my future.”

Francisca E. Oboh-Ikuenobe, Chair, GSA’s Diversity in the Geosciences Committee.

On To the Future scholars.



SPECIAL PAPER 503

Through the End of the Cretaceous in the Type Locality of the Hell Creek Formation in Montana and Adjacent Areas

Edited by Gregory P. Wilson, William A. Clemens, John R. Horner, and Joseph H. Hartman

For over a century, the Hell Creek and Fort Union formations and their constituent fossil biotas have captivated geologists and paleontologists alike. In Montana and adjacent areas, these rocks have become renowned as the type locality for *Tyrannosaurus rex* and the epicenter for debate surrounding the mass extinction of dinosaurs at the Cretaceous-Paleogene boundary. The chapters in this volume represent a surge of field and laboratory research activity that illustrates the impacts of new and refined methods and tools. In tandem, the research questions have evolved to take advantage of the increased precision, quality, and quantity of the data, from determinations of paleoecologies to assessment of ontogenetic sequences, patterns of sedimentation, and basin-level intraformational correlations. Together, the chapters are a major step forward in the quest to mine the rich lode of geologic and biologic history preserved in the strata bounding the Cretaceous-Paleogene boundary.

SPE503, 390 p., ISBN 9780813725031
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Positions Open

HYDROGEOLOGIST
ASSISTANT PROFESSOR
GEOLOGICAL SCIENCES
UNIVERSITY OF IDAHO–MOSCOW

The Department of Geological Sciences at the University of Idaho (UI) is seeking applications for a 9-month, tenure-track position in Hydrology. Applications will be accepted from candidates with research and teaching interests over a wide spectrum of groundwater science applications. Areas of specialization may include, but are not limited to all aspects of groundwater resource evaluation, groundwater hydraulics, hydrogeochemistry, and hydrogeophysics. Tentative start date will be Fall 2014. The candidate must have a Ph.D. in geological sciences or closely related field at the time of employment. Salary Range: $65,000. For more information and to apply, visit http://apptrkr.com/409605 by 15 March. Announcement #10000043970. AA/EOE.

DEPARTMENT HEAD
DEPARTMENT OF GEOSCIENCES
MISSISSIPPI STATE UNIVERSITY

The Department of Geosciences at Mississippi State University invites applications for a Department Head at the rank of Professor. This is a 12-month appointment to begin July 1, 2014, salary commensurate with experience. The successful candidate will provide leadership to the Department's programs in undergraduate and graduate education and research. The Department Head will hold a faculty position in the Department of Geosciences.

The Department Head will be expected to guide all subdisciplines (Geography, Geology, Geospatial Sciences, and Meteorology) and distance learning programs of Geosciences towards greater national and international research and educational recognition. The successful candidate will be expected to attract and mentor the highest quality faculty, strengthen the existing Ph.D., M.S., and B.S. degree programs, and expand the department's interdisciplinary research activities. The Department Head will also oversee daily departmental functions and work with the College of Arts & Sciences and alumni to attract funds and resources.

The successful candidate is expected to have strong leadership qualities. A commitment to collegiality in the Department is very important in this interdisciplinary program. The candidate should serve as an advocate for the department at the college and university levels with regard to departmental programs and initiatives in all sub-disciplines of Geosciences.

Minimum Qualifications: The successful candidate for this position will have an earned Ph.D. in geosciences or a related field, with academic achievements consistent with appointment as a full professor with tenure. Applicants should have a high record of research productivity, teaching credentials, student mentorship, and external funding. Demonstrated leadership and administrative skills and a vision for advancing an interdisciplinary department of geosciences are expected from the successful candidate. Preferred qualifications include knowledge of, or experience with distance learning course delivery as well as research interests that will strengthen, build, or bridge existing programs in Geosciences.

The Department of Geosciences currently has 16 tenure-track faculty members and 8 instructors. The department offers B.S. and M.S. degrees in Geosciences and a Ph.D. degree in Earth and Atmospheric Science within five areas of emphasis: Environmental Geosciences, Geography, Geology, Geospatial Sciences, and Meteorology. In addition to the on-campus programs, our distance learning programs enroll more than 500 undergraduate and graduate students. Further information about the Department of Geosciences can be found at http://geosciences.msstate.edu/.

Interested candidates should submit a Personal Data Information Form (PARF # 7727) online at https://www.jobs.msstate.edu/ along with a cover letter describing their interest in the position, their CV, statements of not more than two pages each describing their leadership philosophy, teaching philosophy, and research interests, and contact information for five (5) references. For further information about this position, please contact Michael Galaty, Search Committee Chair at mgalaty@anthro.msstate.edu. Applications are due March 1, 2014; however, review of files will begin immediately. MSU is a public, land-grant institution and is classified as a "very high research activity" university by the Carnegie Foundation.

ASSISTANT PROFESSOR
ECONOMIC GEOLOGY
NEVADA BUREAU OF MINES AND GEOLOGY

The Nevada Bureau of Mines and Geology (NBMG) at the University of Nevada, Reno, seeks applicants for a tenure-track faculty position focused on hydrothermal mineral deposits. NBMG is a research an d public service unit of the University of Nevada, Reno (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.

The position will be a tenure-track faculty appointment with an academic-year base salary that is competitive with other research universities. Starting date will be July 1, 2014 or shortly thereafter, depending on availability of the successful candidate.

To apply, please visit https://www.unrsearch.com/postings/13967. Please complete the online application and upload a letter expressing your interest in the position and research plans; a complete vita; contact information (names, e-mail and postal addresses, and telephone numbers) for at least three references; and electronic copies of up to three of your publications. Additionally, applicants must submit examples of geologic mapping related to mineral deposits that they have conducted with their application materials. To ensure full consideration, all information must be submitted by March 24, 2014. For further information about NBMG, please consult our website, http://www.nbmg.unr.edu.

Equal Employment Opportunity/Affirmative Action. Women and underrepresented groups are encouraged to apply.

Opportunities for Students

The Dept. of Geosciences, Univ. of Akron, Ohio has assistantships available in fall 2014 for students who have the drive and curiosity to succeed in graduate school. Examples of some of the ongoing research in the department include studies in geobiology, studies of the climate record contained in lake sediments, oceans, and caves, and studies in global biogeochemical cycles. Interested students may contact Dr. John Peck at jpeck@uakron.edu for more information, and apply online at http://www.uakron.edu/gradsch/apply-online/,

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The geoscience community's obligation to its "Last Great Hope": Do geology graduates understand human transformations of Earth systems?

Kristen E. Schmeisser** and **Paul K. Doss, Dept. of Geology and Physics, University of Southern Indiana, Evansville, Indiana, 47712, USA.*

"The Last Great Hope." That is what former GSA President John Geissman called the present generation of geoscience students in his 2011 Presidential Address (Geissman, 2012). He then called for the strengthening and support of the geoscience professoriate as the instructors, mentors, and advisers of tomorrow's leaders and innovators. To those ends we argue that the geoscience community must ensure that all geology students have an understanding of the global-scale processes that are unsustainably modified or degraded by human transformations, and perhaps more importantly, help develop those students' ability to communicate that information to the general public. Furthermore, the geoscience professoriate must enable, encourage, and prepare our undergraduate geology students to speak out against misinformation delivered by a small group of individuals in science and the media who present their personal beliefs against the wealth of peer-reviewed and reproducible data that have resulted in the overwhelming scientific majority conclusion of anthropogenically induced climate change.

Students in the senior geology capstone course at the University of Southern Indiana were generally unaware and uninformed of many global-scale human modifications of Earth's processes (Table 1). Graduating geology students admitted misunderstanding that, without global lifestyle changes, the planet they have studied for the past four years would likely change dramatically during their careers, perhaps becoming *Eaarth* (McKibben, 2008), essentially a *different planet*. Textbooks (e.g., Mann and Kump, 2008), lectures, media, and museum and public land exhibits can provide everyone with accurate and timely information about global environmental change. Yet, if these approaches have not adequately informed the general populous on the fundamentals of global change, shouldn't the geoscience community at least be responsible to inform the next generation of earth scientists about climate change and other anthropogenically aggravated environmental problems?

Ignorance and misunderstandings about environmental transformations amongst geology students are not restricted to senior undergraduates in southern Indiana. Rebich and Gautier (2005) found that upper-division students specifically interested in climate change harbored misconceptions at the beginning of the course that persisted following instruction, including shortwave and longwave radiative processes, changes in temperature, and the greenhouse effect. In the allied field of engineering, Azapagic et al. (2005) found a lack of awareness on a variety of environmental issues, agencies, and sustainability practices. It was also noted that these students believed sustainability to be an issue in the future, rather than of immediate importance. Instruction in geologic thinking, considering differing hypotheses, rates, scales, and variables simultaneously, could do much to enhance understanding of global change (Dodick and Orion, 2003), but simply teaching undergraduates how to think without also introducing them to the spectrum of human transformations will leave them ignorant.

Discussions of human-driven global change, in what many are beginning to refer to as the Anthropocene (Crutzen, 2002), can and should take place in historical geology, mineralogy, petrology, structural geology, sedimentology, stratigraphy, geomorphology, hydrogeology, paleontology, and field courses (Table 1). Although there is no formal accreditation of, or standard for, an undergraduate geology curriculum, there is a generally recognized set of core and elective courses for professional geologists (Williams et al., 2004). And while we have no information about current instances of integrating "humans as geologic agents" across the curriculum, and therefore no assessment of such a curriculum revision, existing core courses can become the vehicle for such integration. Traditional historical geology and paleontology courses, which presumably cover the record of mass extinction events, can include an element investigating the causes and mapping geographical and species distributions of what is now referred to as an anthropogenically induced "sixth extinction" (Barnosky et al., 2011). A traditional sedimentology and stratigraphy course, which presumably covers sedimentation rates and yields, should incorporate an element that quantifies

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Table 1. Anthropogenic modification and degradation of global-scale geological processes, example references, and the relevant curricular elements of a traditional undergraduate geology program

Global-scale geological processes	Global-scale human transformations	Example transformation references	Relevant existing curriculum
Sedimentation	Agricultural and urban soil erosion; reservoir infilling; sediment yield to oceans; damming, dredging, and flood control of rivers; coastal erosion	Wilkinson and McElroy, 2007	Sedimentology, stratigraphy, geomorphology
Water cycle	Storm-water runoff; urban groundwater recharge; groundwater mining	Sharp, 2010	Physical geology, hydrogeology, geomorphology
Geochemical cycles	Fossil fuel emissions and climate change; fertilizer N and P application; ocean acidification; hard rock mining; REE usage; pharmaceuticals and pesticides in groundwater	Rabouille et al., 2001; Tillman et al., 2001; Vitousek et al., 1997	Mineralogy, petrology, economic geology, geochemistry, field course, hydrogeology
Landscape development	Urbanization; deforestation; desertification; mining (mountaintop removal, tar sands, etc); slope steepening and overloading; stream channel straightening; glacial melting (due to climate change)	Hooke et al., 2012	Physical geology, geomorphology, structural geology, field course
Species and habitat distribution	Exotic species introductions; anthropogenic extinctions; habitat destruction; hypoxic "dead zones"; Pacific Ocean "garbage patch"; coral bleaching	Hoegh-Guldberg and Bruno, 2010; Vitousek et al., 1997	Historical geology, paleontology, geochemistry
Earth-surface subsidence	Groundwater withdrawal; oil and gas pumping; deltaic subsidence	Syvitski et al., 2009	Physical geology, historical geology, hydrogeology, petroleum geology

human-induced changes in stream dynamics and fluvial sediment yields (Table 1). Traditional geomorphology and physical geology courses can develop lab exercises that construct spatial data displays of agricultural soil losses, desertification, and dam construction. And traditional courses in hydrogeology and aqueous geochemistry can summarize new sampling results of pharmaceuticals in groundwater, alterations to global cycling of nitrogen, and ocean acidification.

Finally, geology undergraduates need courses directly focused on anthropogenic transformations. Although there is some skepticism about the ability of an undergraduate climate change class to alter individual behavior, students in such a course do make gains in their understanding of global change (e.g., Lombardi and Sinatra, 2012). Undergraduate geology students need incentives to be in the library, in the lab, and in the field pursuing research on global environmental change and Earth processes that have been disrupted by human action. Undergraduate students need to attend and participate in conferences by GSA and other allied science organizations. They need to be reading the literature and the news and understanding the interdisciplinary complexity of global environmental issues. Most importantly, undergraduate students need to be engaging in discussions about what they read and hear. Discussions with their professors, peers, and, ultimately, with their non-expert friends and family will deepen their and the public's understanding of the problems we face.

GSA President George Davis mentioned in his address that the geoscience community is struggling to impact its future workforce (Davis, 2013). What better way to engage the future of our science than to establish a formal pedagogy about anthropogenic global change with the next generation of geologists? If they are indeed the Last Great Hope, then it is a moral obligation to make certain they understand the global effects of human transformations in Earth processes, and, by providing increased opportunities for communication skills practice, to enable them to inform the general public. We do not advocate a wholesale revision of the geology curriculum to an environmental science curriculum. Humans are now widely recognized as a dominant agent of global change across Earth's geological systems. If we teach an integrated curriculum on geology, the study of Earth, we have no option but to integrate human transformations across that curriculum.

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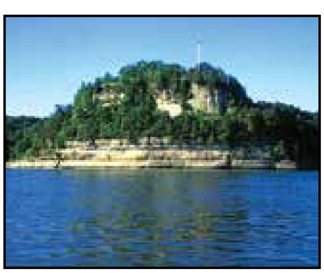

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