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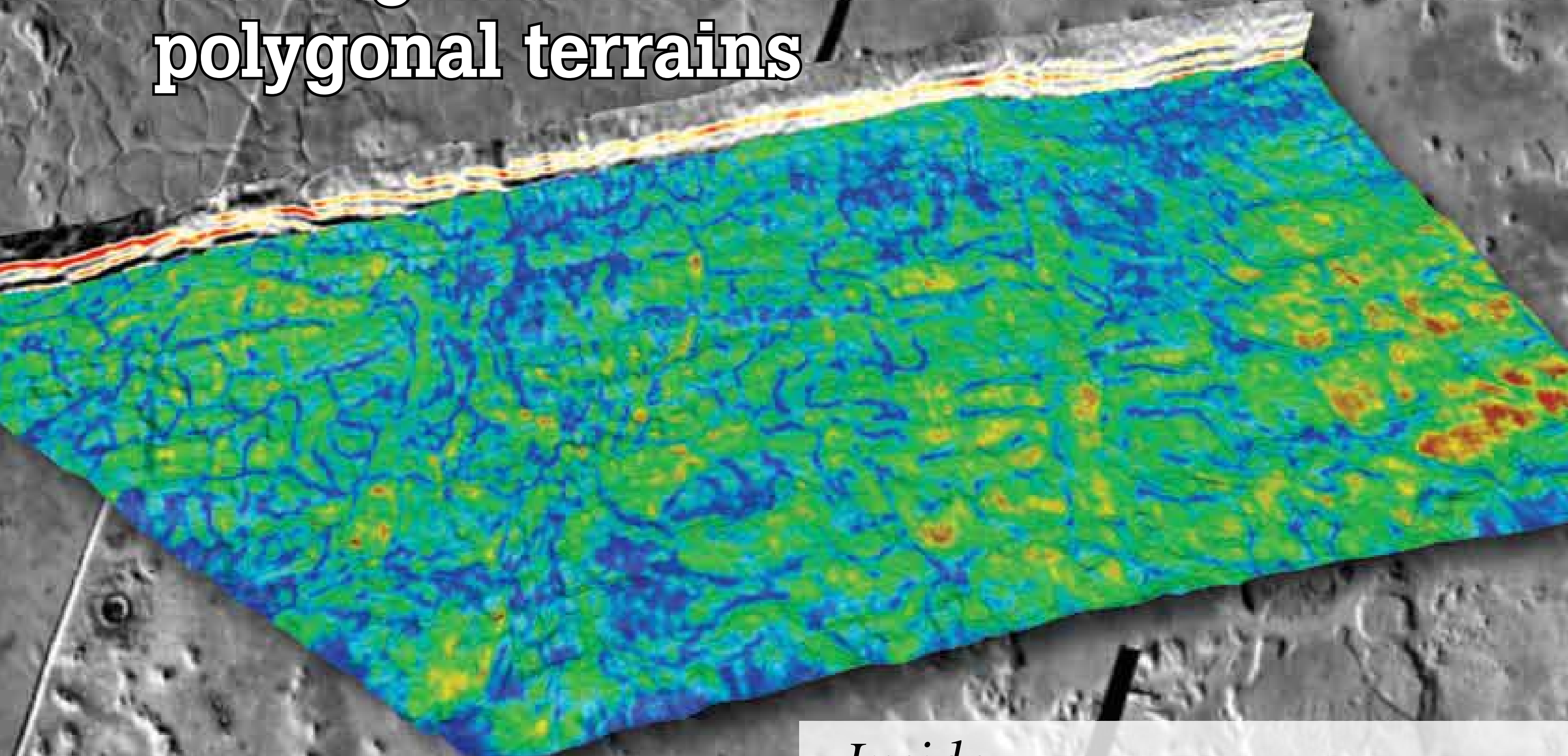
Deep-water polygonal fault systems as terrestrial analogs for large-scale Martian polygonal terrains



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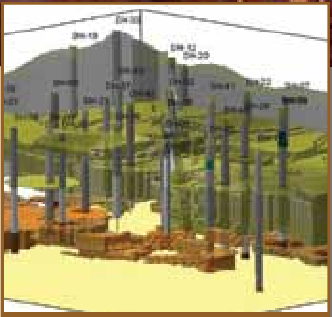

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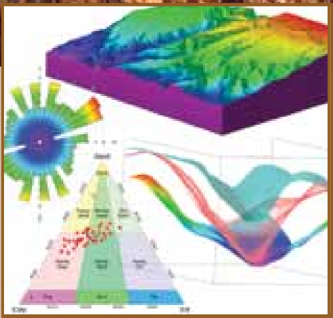

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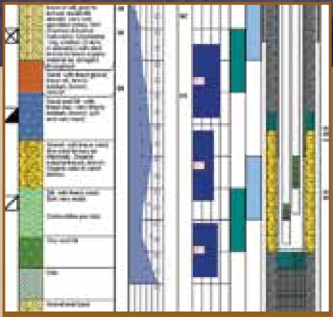

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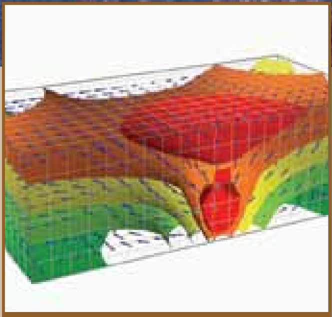

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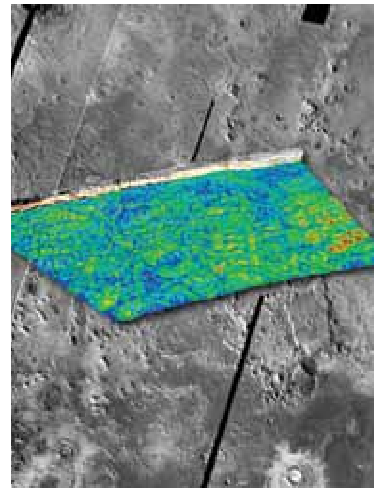
SCIENCE ARTICLE



Cover: Terrestrial deep-water marine polygons (front, color image) are potential morphological and genetic analogs to large-scale Martian polygonal features (grayscale). Front: The terrestrial deep-water polygons are imaged using 3-D seismic-reflection data acquired by the oil and gas industry in offshore Norway (Brygge Fm.). Background: THEMIS imagery shows the character of large-scale Martian polygons in Acidalia Planitia (Vastitas Borealis Formation). See related article, p. 4–9.

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Deep-water polygonal fault systems as terrestrial analogs for large-scale Martian polygonal terrains

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ABSTRACT

Discovery of giant polygonal terrains on Mars has prompted a 30-year debate over how they formed. The prevailing hypothesis is that small-scale Martian polygons formed by thermal contraction, as in terrestrial permafrost environments. Large-scale (>1 km) Martian polygons in the northern plains are visible in THEMIS, MOLA, *Viking*, and *Mariner* data, but how they formed remains enigmatic. We suggest that terrestrial deep-water marine polygons are morphological and perhaps genetic analogs to large-scale Martian polygonal features. The terrestrial, deep-water polygons are imaged in three-dimensional seismic-reflection data acquired by the oil and gas industry in offshore Norway and the Gulf of Mexico.

How deep-water polygonal fault systems form is a debated topic beyond the scope of this work. However, similarities between terrestrial deep-water polygonal fault systems and large-scale Martian polygonal terrains suggest that the latter could have formed during deep-water marine deposition. Deep-water polygonal faults form within fine-grained sediment at shallow burial depths. Increases in slope angles can trigger downslope disaggregation of deep-water polygons and mass wasting (forming debris flows). Physical models indicate that multidirectional extension can cause polygonal features to break up on a slope over a mobile substrate. Some knobby terrains in the Vastitas Borealis Formation seem to originate from disaggregation of large-scale Martian polygonal terrains. These analogies suggest a possible deep-water subaqueous origin for large-scale Martian polygonal terrains and support the idea of a late Hesperian–early Amazonian ocean on the northern plains of Mars.

INTRODUCTION

Polygonal terrains on Mars cover a wide spectrum of scales (Levy et al., 2009; Hiesinger and Head, 2000) and have been linked to a variety of processes, including basalt loading, cooling of volcanic material, tectonic deformation, desiccation, density-driven convection, and thermal contraction (McGill, 1986; McGill and Hills, 1992; Hiesinger and Head, 2000; Buczkowski and McGill, 2002; Buczkowski and Cooke, 2004; Levy et al., 2010). Several decades of detailed observations of the Martian surface have allowed researchers to conclude that small-scale Martian polygons (typically <25 m in diameter) can form by thermal contraction processes similar to those in terrestrial permafrost environments (Mutch et al., 1977; Mellon, 1997; Head et al., 2003; Levy et al., 2008). However, formation of large-scale Martian polygons (hundreds of meters to kilometers in diameter) (Fig. 1) is not well explained by permafrost processes and remains highly speculative (Lane and Christensen, 2000; Hiesinger and Head, 2000; Cooke et al., 2011). Lane and Christensen (2000) postulated that Rayleigh free convection within a thick, catastrophic flood deposit on the northern plains of Mars formed large-scale polygonal terrains. In contrast, Hiesinger and Head (2000) proposed that tectonic uplift of an ancient Martian basin floor was the ultimate trigger for forming large-scale Martian polygons. Most recently, Cooke et al. (2011) suggested that giant polygons in Utopia Planitia formed by volumetric compaction of wet, fine sediments along the slopes of buried basement in an ancient Martian ocean. We support the idea that large-scale Martian polygons on the northern plains of Mars formed in deep water in a late Hesperian–Amazonian ocean (Lucchitta et al., 1986; Baker et al., 1991; Parker et al., 1989, 1993; Head et al., 1999; Cooke et al., 2011). We strengthen the argument by presenting striking geomorphological similarities between terrestrial deep-water, polygonal fault systems and what we consider to be their Martian counterparts (Figs. 1–3). We use recently acquired high-resolution, three-dimensional seismic data from offshore Norway and the Gulf of Mexico to document in detail the geomorphology of deep-water polygonal systems.

Seismic surveys have greatly improved our ability to study terrestrial deep-water environments (Cartwright et al., 2003) (Figs. 2 and 3) and made available analogs that might be relevant to past Martian environments (Moscardelli and Wood, 2011; Burr, 2011). More than 20 examples of terrestrial, kilometer-scale, marine polygonal fault systems have been studied on passive margins or within cratons (Cartwright and Dewhurst, 1998). On Earth, the genesis of deep-water polygonal faults has been attributed to a variety of mechanisms, including gravity collapse, density inversion, syneresis, gravitational loading, fluid expulsion, low coefficients of residual friction, and diagenesis (Cartwright et al., 2003; Goulty and Swarbrick, 2005; Goulty, 2008; Cartwright, 2011). The specific physical or chemical processes that created large polygons on Earth or Mars are beyond the scope of this paper, however, and the reader is referred to Hiesinger and Head (2000), Cartwright et al. (2003), and Cartwright (2011) for summaries. Our paper (1) provides a deep-water terrestrial analog that might help elucidate the environment of deposition of large-scale Martian polygonal terrains; (2) illustrates geomorphological complexities within deep-water environments and applies these to Mars; and (3) highlights how modern seismic data from industry can elucidate purely academic problems in deep-water environments and on other planets.

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DEEP-WATER POLYGONAL FAULT SYSTEMS ON EARTH

Polygonal fault systems are widespread in the North Sea and the Norwegian Sea (Cartwright and Dewhurst, 1998). Deep-water polygonal faults form in marine sediments having high porosities and low permeabilities; these are commonly but not exclusively composed of ultrafine-grained smectitic claystones or carbonate chalks (Cartwright and Dewhurst, 1998). Deep-water polygonal systems within units that have diverse mineralogy suggest that particle size might be more important than composition in their formation, but lithology also plays a crucial role. Figure 2 shows seismically imaged polygonal faults from the deep-water (>500 m) eastern margin of the Vøring Basin in offshore Norway. The Eocene–Oligocene Brygge Formation is clay-rich and has an average thickness of 450 m (Fig. 2A). Near its base, polygons reach 1 km in diameter (Fig. 2B). Higher in the unit, polygons are smaller and more abundant (Fig. 2C). Deep-water polygonal faults such as these are attributed mainly to syneresis, low coefficients of

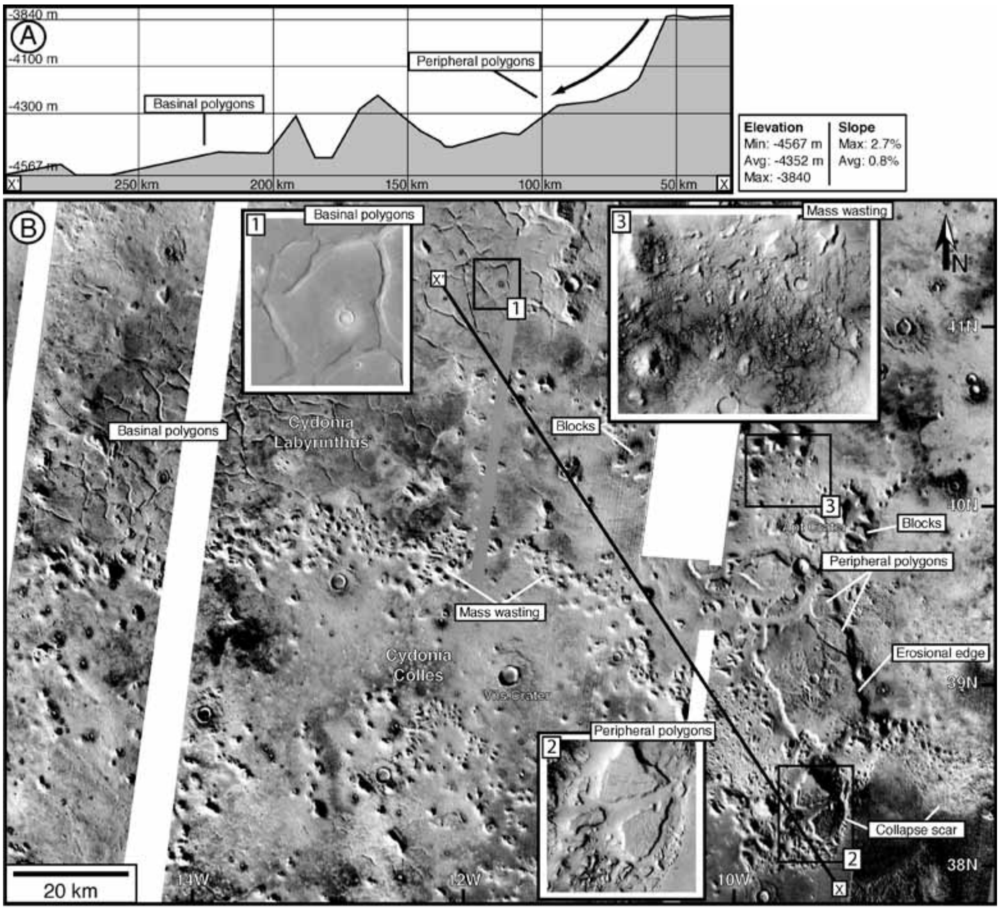

Figure 1. (A) Profile using THEMIS and MOLA imagery showing topographic differences between areas of large-scale Martian peripheral and basinal polygons in Acidalia Planitia. This profile was used to calculate maximum (2.7%) and average (0.8%) slope values. (B) Map showing basinal and peripheral polygons in Acidalia Planitia.

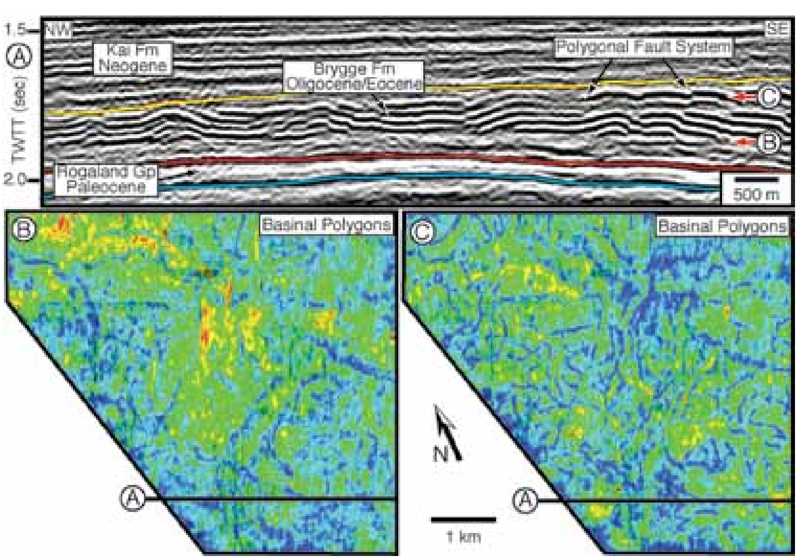

Figure 2. Seismic profile and maps of root mean square of the seismic wave amplitudes showing two levels of a deep-water polygonal fault system within the Eocene-Oligocene Brygge Formation (offshore Norway). Seismic data courtesy of the Norwegian Petroleum Directorate. TWTT—two-way travel time.

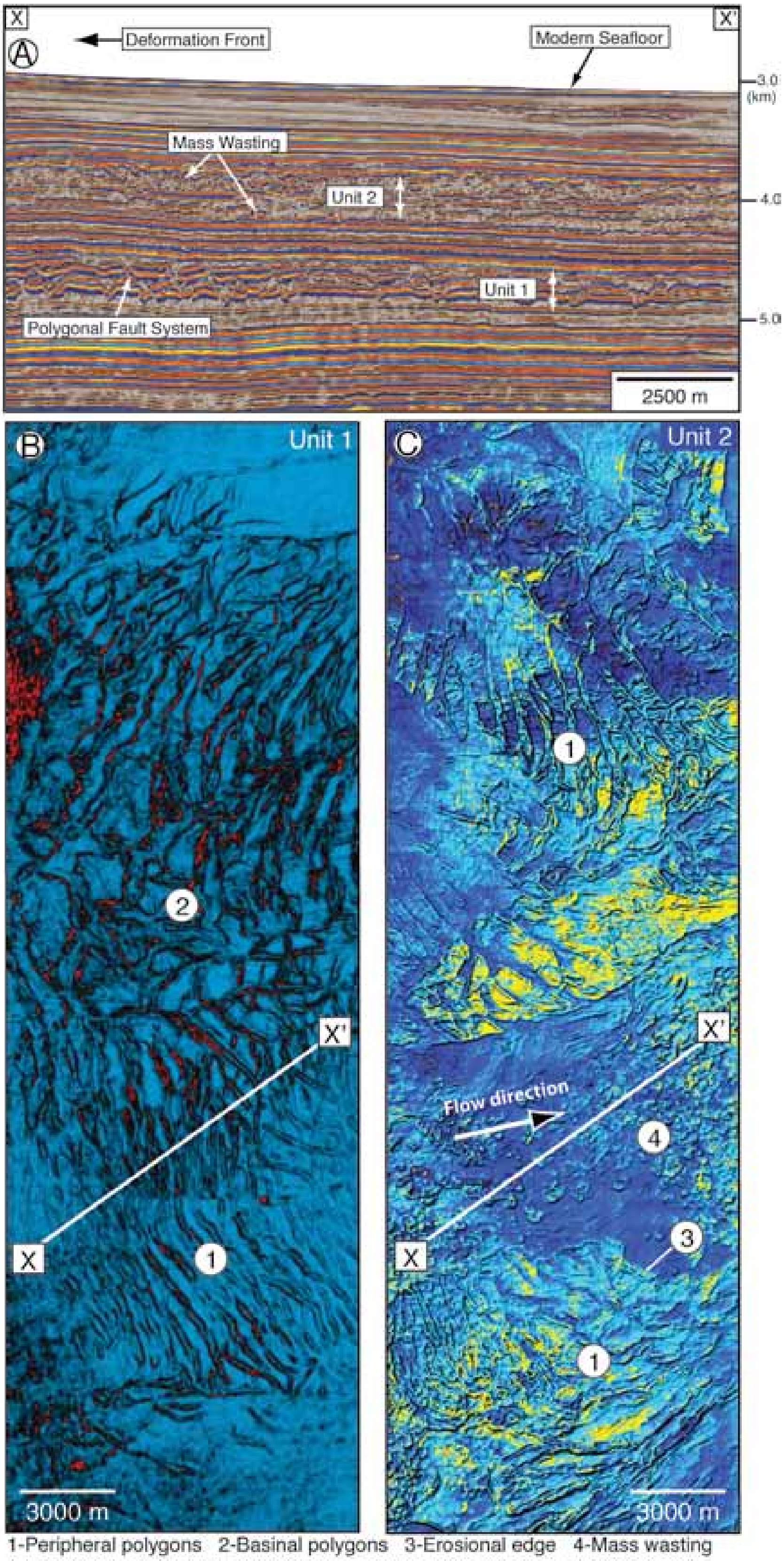

Figure 3. (A) Seismic profile, (B) semblance attribute map, and (C) spectral decomposition map on two different deep-water polygonal fault systems within Cenozoic strata of the northern Gulf of Mexico. Semblance attributes measure lateral changes in the seismic response caused by variations in structure and stratigraphy. Spectral decomposition breaks the seismic signal into its dominant frequency components to highlight structural and stratigraphic features. Seismic data courtesy of CGGVeritas.

friction, or diagenetically induced shear failure (Cartwright et al., 2003; Goulty, 2008; Cartwright, 2011). Most of the mechanisms envisaged act soon after deposition or at shallow burial depths (Cartwright et al., 2003; Goulty, 2008; Cartwright, 2011). Syneresis is the subaqueous contraction of gels in flocculating clays as water is lost by compaction or by an increase in salinity. The high clay content in the Brygge Formation could form gels during deposition because of the micron size of its particles, so syneresis is theoretically feasible (Cartwright et al., 2003). Goulty (2008) suggested instead that low coefficients of residual friction in fine-grained sediments are the key to the development of deep-water polygonal faults. However, residual friction only applies after initial slip occurs, so what triggered the faults remains obscure (Goulty, 2008). Recent experimental work (Shin et al., 2008) provides an alternative explanation in which diagenesis of clay-rich sediments can lead to shear failure under low confining stresses, triggering the formation of polygonal fault systems (Cartwright, 2011). Regardless of the genetic mechanism, there is a consensus that deep-water polygonal faults typically form (1) in sequences of very fine grained sediments; (2) in marine basins of >500 m water depth; and (3) at shallow burial depths (Cartwright et al., 2003; Goulty, 2008). Some deep-water polygonal faults in the Vøring Basin have sea-floor expression (Cartwright et al., 2003, their figure 15), indicating that thick overburdens are not necessary to form the polygonal pattern (Cartwright and Dewhurst, 1998; see their figure 10).

Another example of deep-water polygonal fault systems is observed seaward of the Sigsbee Escarpment, which marks the limit of shallow salt canopies in the Gulf of Mexico (Fig. 3). The Neogene polygonally faulted units there have an average thickness of 500 m (Fig. 3A), and the polygons can be more than 3 km wide (Fig. 3B). Onlaps and truncations by overlying units indicate that these polygons formed shortly after sediments were deposited in the basin at water depths that exceeded 1000 m. Unit 1 formed when the canopy front was 4 km north of the northern edge of visible polygons. A map (Fig. 3B) shows the typical interlocking shapes of deep-water polygons. However, faults located next to the main polygons have a strong northeast strike in response to advance of the salt canopy and subsequent southward

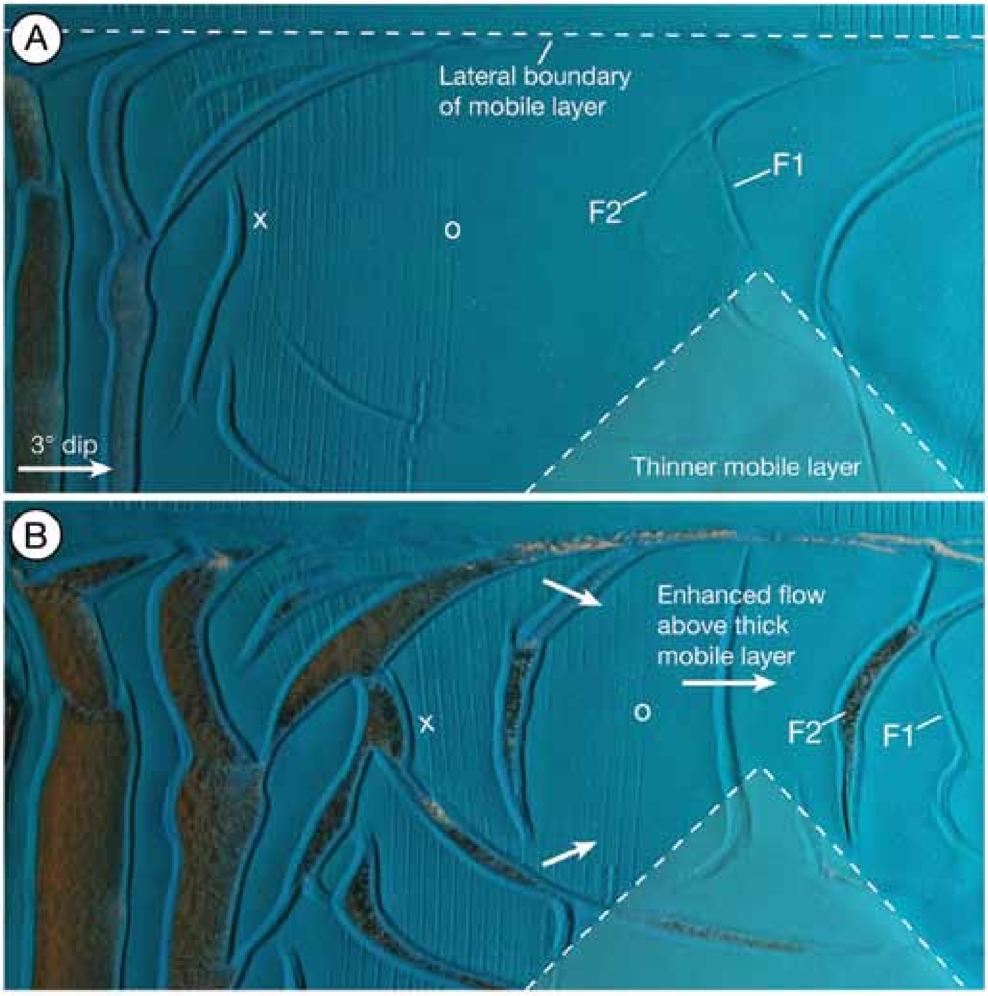

Figure 4. Physical model showing transition from (A) normal faulting to (B) separated polygons under multidirectional extension triggered by gravity. The model comprises a brittle layer of dry blue sand overlying a viscous layer of transparent, colorless silicone polymer (polydimethylsiloxane). Initial fault patterns are controlled by the surface dip of the model and the lateral boundaries of the mobile unit (A). Thickness variations within the mobile unit result in multidirectional extension due to enhanced flow within the thicker mobile unit, separating and rotating the polygons (B). F1 and F2—faults; x and o—arbitrary marker points.

tilting of the seafloor. Unit 2 formed when the canopy front had advanced 1 km closer, building a steeper slope that disrupted the polygonal blocks and caused downslope mass wasting as debris flows (Fig. 3C). Partly deformed polygons within unit 2 record a stage of disruption intermediate between intact glide blocks and debris flows (Fig. 3C). Deep-water polygonal faults are commonly associated with mass wasting units (slides, slumps, and debris flows) (Fig. 3C) (Cartwright, 2011). Numerical models show that buried topography can control the geometry of giant polygons during the faulting (Cooke et al., 2011). A physical model simulates a later stage where the polygons are disrupted. The physical model shows how gravity gliding alone can radically deform polygonal fault systems if a brittle, faulted layer overlies a mobile substratum and both are gently tilted (Fig. 4A). The pattern of extension is strongly influenced by (1) surface dips supplying a gravitational component of shear stress; and (2) thickness variations in the mobile substratum, which cause spatial and temporal variations in the extension rate (Fig. 4B). Thus multidirectional extension in response to surface dip and thickness variations is one way to modify giant polygonal fault systems under gravity on Earth.

SIMILARITIES BETWEEN MARTIAN AND TERRESTRIAL DEEP-WATER POLYGONS

Large-scale polygonal terrains are common on the northern plains of Mars (Fig. 1) in Elysium, Acidalia, and Utopia Planitia (Lucchitta et al., 1986). The diameter of large-scale Martian polygons is variable (1–32 km), as are the widths of troughs defining their polygonal shapes (200–800 m) (Hiesinger and Head, 2000). Large-scale polygons on Mars (Fig. 1) resemble deep-water polygons on Earth (Figs. 2 and 3), especially in the distinction of two types of polygons. Basinal polygons have a uniform pattern, whereas peripheral polygons are more discontinuous and irregular (Figs. 1 and 3). Basinal polygons are present on Mars (Cydonia Labyrinthus in Acidalia Planitia and Utopia Planitia) and Earth (Brygge Formation in offshore Norway; Fig. 2 herein; unit 1 in the Gulf of Mexico; Fig. 3B herein). On Earth, basinal polygons are found where slopes are gentle (<0.5°) and younger deformation is absent, so the original geometry is preserved (Figs. 2 and 3B). On Mars, basinal polygons formed mostly on the northern plains, far from interpreted paleoshorelines or outflow channel outlets (Fig. 1). Peripheral polygons on Earth formed above steeper (>0.5°) slopes affected by gravity-induced sediment deformation (Fig. 3C). Unit 2 in the Gulf of Mexico clearly shows peripheral polygons progressively disrupted to form debris flows (Fig. 3C). Our physical model suggests that peripheral polygons can evolve in a brittle layer under the influence of a surface slope and a mobile substrate of uneven thickness (Fig. 4). Similar peripheral polygons on Mars occur near possible paleoshorelines and within outflow channels (e.g., Chryse and Hydraotes Chaos). Peripheral polygons also occur where slopes are locally steeper (e.g., Acidalia

Mensa and Acidalia Colles) (Fig. 1). The polygonal terrain on the southeast corner of Figure 1B (Acidalia Planitia) resembles that in unit 2 in the Gulf of Mexico (Fig. 3C), where the polygons were disrupted and reduced to mass-wasting deposits, and in the physical model (Fig. 4) in which these polygons were torn apart and rafted under gravity.

DISCUSSION

The origin of small-scale Martian polygons has convincingly been linked to thermal contraction (Mellon, 1997; Levy et al., 2010). However, the origin of large-scale and older Martian polygonal terrains on the northern plains of Mars remains debatable (Hiesinger and Head, 2000; Lane and Christensen, 2000; Cooke et al., 2011). Lucchitta et al. (1986) proposed that large-scale Martian polygonal terrains formed when sediment slurries shed from the highlands were rapidly deposited and froze on an ancient ocean locally covered by ice on the northern plains. Lane and Christensen (2000) suggested that to form a 5-km-diameter Martian polygon, the system would need an ~1.1- to 1.5-km-thick freely convecting layer. This anomalously thick layer could have been a thick, water-saturated, sedimentary package that accumulated rapidly from catastrophic flooding linked to outflow channels (Lane and Christensen, 2000). In Utopia and Acidalia Planitia, these polygons are late Hesperian–Amazonian in age, coeval with outflow channels and the Vastitas Borealis Formation (Lucchitta et al., 1986; Werner et al., 2011). Terrestrial deep-water polygonal faults can develop within hosts up to 1 km thick, but their formation is linked to syneresis, low coefficients of residual friction, and/or diagenetically induced shear failure instead of thermal contraction or convection (Cartwright et al., 2003; Goulty, 2008; Cartwright, 2011). We concur with a subaqueous origin for Martian polygonal terrains (Lucchitta et al., 1986; Cooke et al., 2011), but based on terrestrial analogs (Cartwright et al., 2003; Goulty, 2008), we infer an alternative mechanism that does not require contraction by freezing or upwelling by convection. Recent radar data from the MARSIS/Mars Express indicate that the dielectric constant of the Vastitas Borealis Formation is low enough to be attributed to widespread deposition of aqueous or icy sediments on the northern plains (Mouginot et al., 2012). We infer that Martian polygonal terrains formed shortly after sediments were deposited as sediment slurries on an ocean floor that then rapidly expelled pore fluids. Large-scale Martian polygons then formed subaqueously on this substratum by syneresis (Cartwright et al., 2003; Cooke et al., 2011) in response to low coefficients of friction on fault planes (Goulty, 2008) or by diagenetically induced shear failure (Cartwright, 2011). We agree with the hypothesis of Cooke et al. (2011) that gravitationally induced extension controlled by buried topography influenced the formation of large-scale Martian polygonal terrains. Based on our physical model, we suggest that polygonal terrains can be severely disrupted by extension where surface dips are increased (Fig. 4).

Regardless of how they formed, large-scale Martian basinal polygons are preserved where slopes were low (e.g., Cydonia Labyrinthus and Utopia Planitia) (Fig. 1). Intact, deep-water, polygonal fault systems are also preserved on Earth on gentle slopes (Fig. 2). In contrast, large-scale, Martian peripheral polygons formed near outflow channel outlets where steeper slopes induced gravitational instability (Fig. 1). Deformation of giant Martian polygons due to slope changes can explain why polygonal and knobby terrains commonly coexist in the northern plains (Fig. 1) and in terrestrial deep-water environments (Fig. 3C). Large boulders and rubble piles overlying much of the Vastitas Borealis and Scandia formations have been interpreted as incompatible with marine deposition (McEwen et al., 2007). However, terrestrial deep-water mass-wasting units contain rafted blocks as large as 3 km^2 in area and at least 100 m thick (Macdonald et al., 1993; Dunlap et al., 2010; Jackson, 2011). Mass-wasting in deep water can catastrophically mobilize huge volumes of sediment in highly efficient plastic flows containing both fine-grained and coarse-grained sediments (Moscardelli and Wood, 2008).

CONCLUSIONS

Hiesinger and Head (2000) have argued that deep-water polygonal fault systems are not an appropriate analog for large-scale Martian polygonal terrains because the terrestrial polygons are considerably smaller (<1 km) than those on Mars. The scale of terrestrial deep-water polygons is in fact comparable to that of large-scale Martian polygons (Figs. 2 and 3). Our study and that of Cooke et al. (2011) suggest that deep-water (>500 m) polygonal fault systems are appropriate analogs for large-scale Martian polygons. We infer that large-scale polygonal terrains on the northern plains of Mars most likely formed under deep-marine conditions (>500 m water depth) because of (1) geomorphologic similarities between large-scale Martian polygonal terrains and deep-water polygonal fault systems on Earth; (2) geomorphologic evidence of a late Hesperian–Amazonian ocean on the northern plains of Mars (Baker et al., 1991; Parker et al., 1989, 1993; Head et al., 1999; Clifford and Parker, 2001; Moscardelli and Wood, 2011; Mouginot et al., 2012); (3) the requirement that high volumes of water were needed to form outflow channels (Clifford and Parker, 2001); and (4) similarities between peripheral polygons and polygons formed by multidirectional extension in physical models. Despite the debate concerning the exact genetic mechanism for the formation of terrestrial deep-water polygonal faults, competing hypotheses are compatible with a deep-marine origin (Cartwright et al., 2003; Goulty, 2008; Cartwright, 2011). Additionally, most authors agree that large-scale polygons formed soon after sediment was deposited on both Earth and Mars (Lane and Christensen, 2000; Cartwright et al., 2003; Goulty, 2008; Lucchitta et al., 1986). Irrespective of the mechanisms forming the polygons, these lines of evidence point to a deep-water setting on the northern plains of Mars during late Hesperian–Amazonian times.

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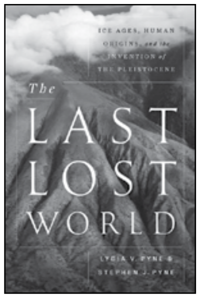

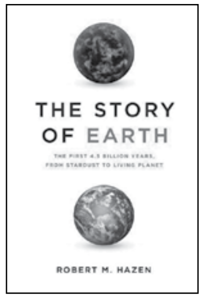

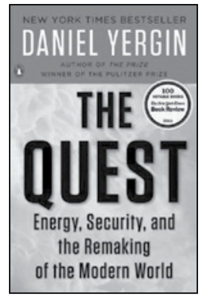

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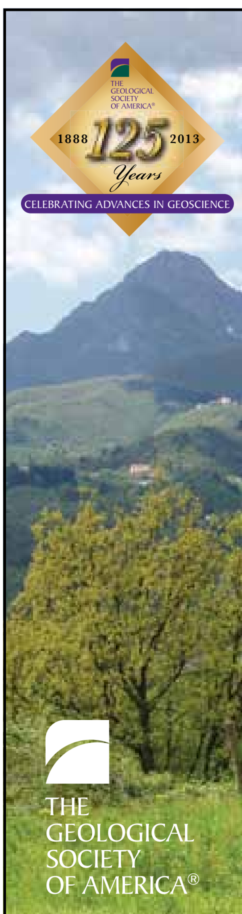

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Field Forums are designed to capture the essence of exciting discoveries or controversial topics via forays into the field for *on the spot* discussions of a particular geologic feature or area. This is both an opportunity to get out into the field and to bring together experts on the topic at hand to exchange current knowledge, ideas, and theories. Recent Field Forum locations include Samos, Greece; Northern Owens Valley and the Volcanic Tableland, California, USA; and the Canadian Shield.

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GEOLOGIC PAST

Highlighting Articles from Past Issues of *GSA Bulletin*

How Do You Solve a Problem Like Mars?

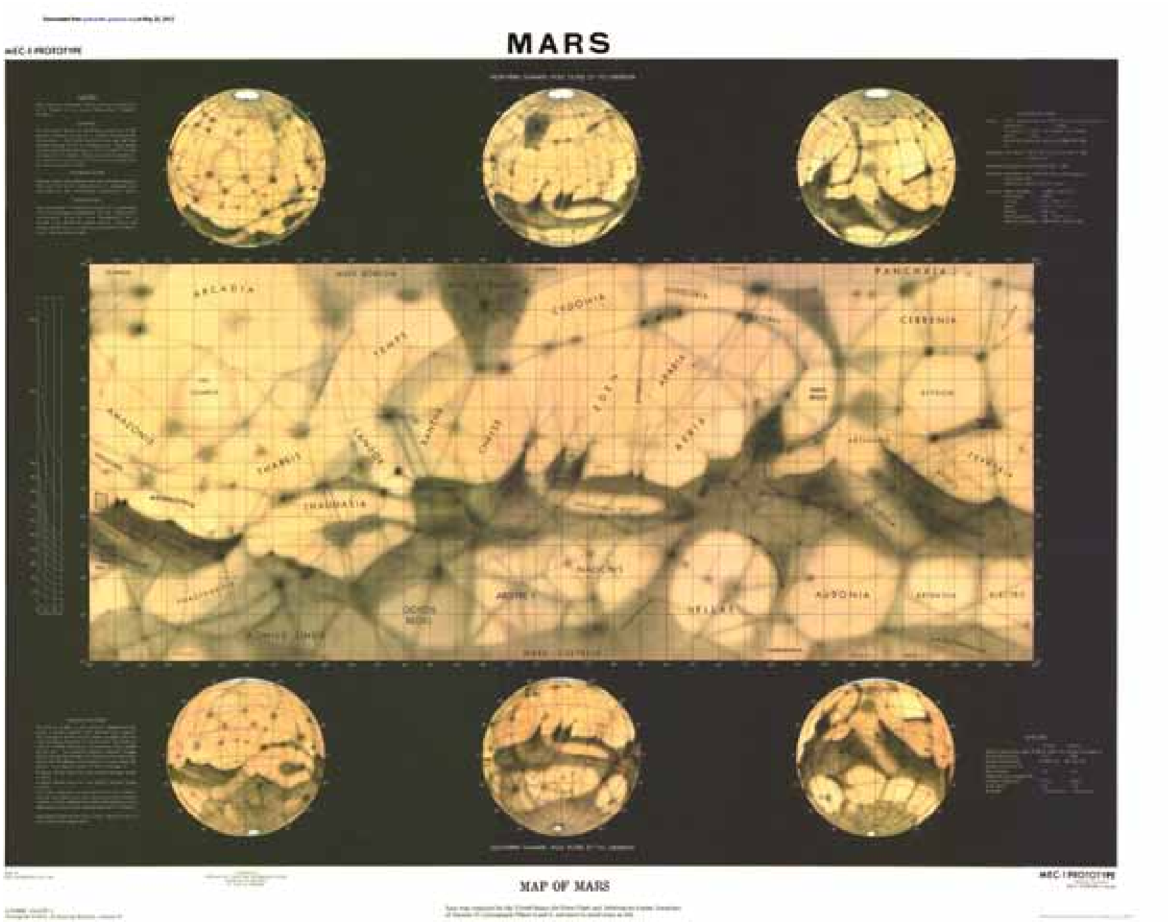
Alden A. Loomis, *GSA Bulletin*, October 1965

In his paper, "Some Geologic Problems of Mars" (v. 76, p. 1083–1104), Alden A. Loomis presents the results of an early phase of research sponsored by NASA and carried out at Cal Tech's Jet Propulsion Laboratory. The paper includes a "map" of Mars (his Plate 1), which was initially produced from multiple *Mariner IV* images by the U.S. Air Force's Aeronautical Chart and Information Center in 1963. That figure is reproduced here.

Loomis begins his article by marking the introduction of geology to the planetary science arena and justifies its integral role in the study of Mars:

> Prior to the last few years, most of the scientific thought concerning the other planets has been in the fields of astronomy and chemistry. … Geologists, however, have recently begun to take an active part in the planning and experimentation for the exploration of the planets. The reason for this is obvious: the evolution of a planetary body is recorded largely in its rocks, its response to seismic waves, and its pattern of outward heat flow through the surface. Also, biological and meteorological investigations, although they are of interest in themselves, may require mineralogical and topographic data to be completely meaningful.
>
> It is of much interest, then, for geologists to ask what can and should be learned from planetary exploration—what information will be most value to the advancement of man's understanding of his own environment as well as to the understanding of more exotic environments. (p. 1083–1084)

The paper then goes into great detail about the knowledge of Mars at that time, including the question of its topography, and Loomis addresses the nature of the evidence for life and seasonality on the planet. His article is available online at gsabulletin.gsapubs.org/content/76/10.toc/1083.abstract.



Kelly A. Kryc

From Field Work to Field Hearings

Because this report is read primarily by earth scientists, I am sure that it comes as no surprise that one of my favorite parts of being a researcher was the field work. I lived for those opportunities. It was the incentive to keep going to the lab every day to process thousands of sediment samples and the reward for pleading with the lab instruments to *just please cooperate*. The hardest part of leaving academia for a career in program management, and now science policy, was leaving the promise of a lifetime of field work behind. I still hope that my last trip to Antarctica in 2004 wasn't actually my last.

While I no longer work in the field, my recent experiences with the Senate Committee on Energy and Natural Resources (ENR) have introduced me to the concept of the *field hearing*, which I think could go a long way toward filling my field-work void. Woodrow Wilson once said, "Congress in session is Congress on public exhibition, whilst Congress in its committee rooms is Congress at work." There are several different kinds of Congressional Committee hearings that serve specific purposes. Each is described in more detail below, as defined by Koempel and Schneider in the Congressional Deskbook[1].

1. **Legislative Hearings** are held to hear testimony on bills that have been introduced and referred to the Committee or to gather information to draft legislation (recent ENR example on Senator Bingaman's Clean Energy Standard Act of 2012: www.energy.senate.gov/public/index.cfm/featured-items?ID=1cac9909-e86f-4486-89d5-a13a763ad6ee).
2. **Oversight Hearings** are convened for the Committee to review federal agencies or government programs (recent ENR example: Consolidating the Office of Surface Mining within the Bureau of Land Management: www.energy.senate.gov/public/index.cfm/hearings-and-business-meetings?ID=78004e99-3afa-4b79-82c9-fd1a8b1c4ac2).
3. **Investigative Hearings** are opportunities for the Committee to explore a topic of interest that may not be directly related to legislation. These hearings can also be held if there is evidence of criminal activity (recent ENR example: Gasoline prices: www.energy.senate.gov/public/index.cfm/hearings-and-business-meetings?ID=25dc6776-a6f1-4f58-b2b4-ee418fc0ecd4).
4. **Confirmation Hearings** are held to consider presidential appointees (recent ENR example: Arunava Majumdar as Under Secretary of Energy: www.energy.senate.gov/public/index.cfm/hearings-and-business-meetings?ID=d19d409a-3d26-41f5-bec6-a2c47da281e9).
5. **Field Hearings** are held outside of Washington, D.C., and can be legislative, oversight, or investigative in nature (recent ENR example: U.S. Navy Energy and Water Policies: www.energy.senate.gov/public/index.cfm/hearings-and-business-meetings?ID=aa329d7d-6a30-4d27-8af8-a3e943e4e00a).

Because of the broad range of subjects I cover within the Committee, I have already had the opportunity to contribute to two field hearings during my fellowship. When I first learned about field hearings, I envisioned Senators, staff, and witnesses on a field trip together (all wearing hard hats, of course) to learn more about a site or subject. In reality, a field hearing looks and feels just like every other hearing conducted by the Senate with respect to formality and decorum.

The first field hearing I worked on (and mentioned in my previous report [*GSA Today*, v. 22, no. 3, p. 26]) was held in Charleston, West Virginia, to examine Marcellus Shale Gas development and production. The second was convened by the Subcommittee on Water and Power on 12 March in Norfolk, Virginia, aboard the *USS Kearsarge* (the first hearing aboard a ship in more than 50 years) to hear testimony about the U.S. Navy's energy and water policies. This hearing will stand out as a highlight of my fellowship year with the Committee.

The morning of the hearing, the participants, including Senator Jeanne Shaheen (D-NH), Senator Mark Warner (D-VA), and former Virginia Senator John Warner (Warner also served as the Secretary of the Navy during the Nixon administration), convened at the Senate office buildings to be transported to Andrews Air Force Base, where we caught a military air flight to Norfolk. I sat across the aisle from former Senator Warner and was treated to his recollections of working for President Nixon and attending law school at the University of Virginia with Robert F. Kennedy. Since retiring from the Senate, Warner has been a tireless advocate for achieving national security and energy independence through implementing energy efficiency policies and adopting clean energy technologies within the Department of Defense (DOD).

Once we arrived, we were briefed by representatives of the Navy and Marine Corps, who demonstrated the clean energy technologies adopted in Iraq and Afghanistan that have not only saved taxpayer dollars but have also saved lives. What struck me

[1]Koempel, M.L., and Schneider, J., 2007, Congressional Deskbook: The Practical and Comprehensive Guide to Congress (fifth edition).

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most during these conversations was that the people we were speaking with had actually been implementing the new clean energy technologies in the theater of war. They sincerely believed that these technologies were making a difference in their ability to defend our country. They weren't primarily adopting them because they were "green" or helped combat climate change. They adopted them because these technologies require less resupply of fuel and water in remote locations; they are quiet and less detectable; they work; and they save lives. It was a pretty powerful endorsement from a group of people who admitted they were less than enthusiastic about making the change in the first place.

The hearing highlighted the Department of the Navy's (DON) clean energy goals to help it attain both energy security and energy independence, and this included the following:

1. **Energy Efficient Acquisition:** DON will make energy efficiency and overall energy footprint a fundamental factor in acquisitions and contract awards;
2. **Sail the "Great Green Fleet":** The "Great Green Fleet" is a carrier strike group of nuclear ships and hybrid electric ships and aircraft that run on biofuel. DON's objective is to demonstrate the fleet in local operations by 2012 and sail it by 2016;
3. **Reduce Non-Tactical Petroleum Use:** DON will reduce petroleum use in the commercial fleet by 50% by 2015 by using hybrid, electric, and flex-fuel vehicles;
4. **Increase Alternative Energy Ashore:** By 2020, alternative fuel sources will provide at least 50% of DON's shore-based energy requirements, and 50% of their installations will be net-zero;
5. **Increase Alternative Energy Use DON-Wide:** 50% of DON's total energy consumption will be derived from alternative sources.

The hearing included three panels of witnesses. Panel One began with the Secretary of the Navy, Ray Mabus. Panel Two featured former Virginia Senator John Warner. Panel Three included a mix of Navy staff who oversee energy issues: Deputy Assistant Secretary of the Navy Thomas Hicks (energy); Vice Admiral Philip Cullom, Director, U.S. Navy Task Force Energy; Major General James Kessler, Commander, Marine Corps Installations Command; Rear Admiral Townsend Alexander, Commander, Navy Region Mid-Atlantic; and Col. Robert Charette, Director, U.S. Marine Corps Expeditionary Energy Office. An audio recording of the hearing and the testimony of the witnesses is available at the ENR website (www.energy.senate.gov/public/index.cfm/hearings-and-business-meetings?ID=aa329d7d-6a30-4d27-8af8-a3e943e4e00a). Below is some background information that highlights the critical role the Department of Defense (DOD), and specifically the Department of the Navy, is playing in advancing a clean energy agenda.

In 2011, the United States required ~7 billion barrels of petroleum, equal to 21% of total world petroleum consumption, to meet its energy needs. On average, the federal government accounts for 2% of the total annual U.S. consumption. By way of example, in Fiscal Year 2008, 93% of this petroleum was used by DOD. DON accounted for ~34% of total DOD petroleum use. DON's overall petroleum use can be broken down into maritime (38%), aviation (40%), expeditionary (16%), and shore (6%) mission domains (see references at the end of this article).

DON has been a leader in developing new tools to procure alternative fuels. They have chosen to pursue these alternatives to improve their operational effectiveness by reducing their potential risk by depending upon just one source of fuel. DON further concludes that by increasing their use of alternative fuels, they will bear less risk due to price volatility and security of supply. For example, they argue that it costs them US$31 million in extra fuel costs for every dollar increase in the cost of a barrel of oil. By investing in energy innovation and clean energy, DON attests that they can help DOD respond to these energy challenges while simultaneously advancing the President's agenda to achieve energy security and independence by reducing the nation's dependence on fossil fuels.

Many Senators and Representatives applaud the Navy's efforts, but there are detractors as well. Some question how the Navy estimates the future price, price volatility, and future availability of both oil and alternative fuels. It may be difficult to critique either perspective until an evaluation can be made of the benefits of alternative fuels (e.g., potential decreased price volatility, diversified suppliers, etc.) versus the costs (e.g., R&D investment, uncertain future price of biofuels, etc.). Others question whether it is DOD's place to make these investments at all. To these detractors, I would ask if they also object to the DOD's role in developing the Internet, GPS, semiconductor computer chips, and flat-screen TVs. Regardless of your position on these issues, from my perspective, the DOD continues to be at the forefront of innovation in this country and, in this case, I feel pretty good about hanging up my field-work hat and trading it in for a Senate field hearing hat. I still would have liked a hard hat though.

For more information about the Navy's energy policies, check out DON's Energy Program for Security and Independence, http://greenfleet.dodlive.mil/files/2010/04/Naval_Energy_Strategic_Roadmap_100710.pdf, and the Pew Project on National Security, Energy, and Climate's report, "From Barracks to the Battlefield: Clean Energy Innovation and America's Armed Forces," www.pewenvironment.org/uploadedFiles/PEG/Publications/Report/DoD-Report_FINAL.pdf.

Editor's note: Since Kelly submitted this article, both the Senate and House Armed Services Committee voted to limit the DOD's biofuels purchasing power, which could have important implications for continued investment by the DOD.

This manuscript is submitted for publication by Kelly A. Kryc, 2011–2012 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. G11AP20221. 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. Kryc is serving on the staff of the Senate Committee on Energy and Natural Resources and can be reached at Kelly_Kryc@energy.senate.gov.

New 2012–2013 GSA-USGS Congressional Geoscience Fellow Named

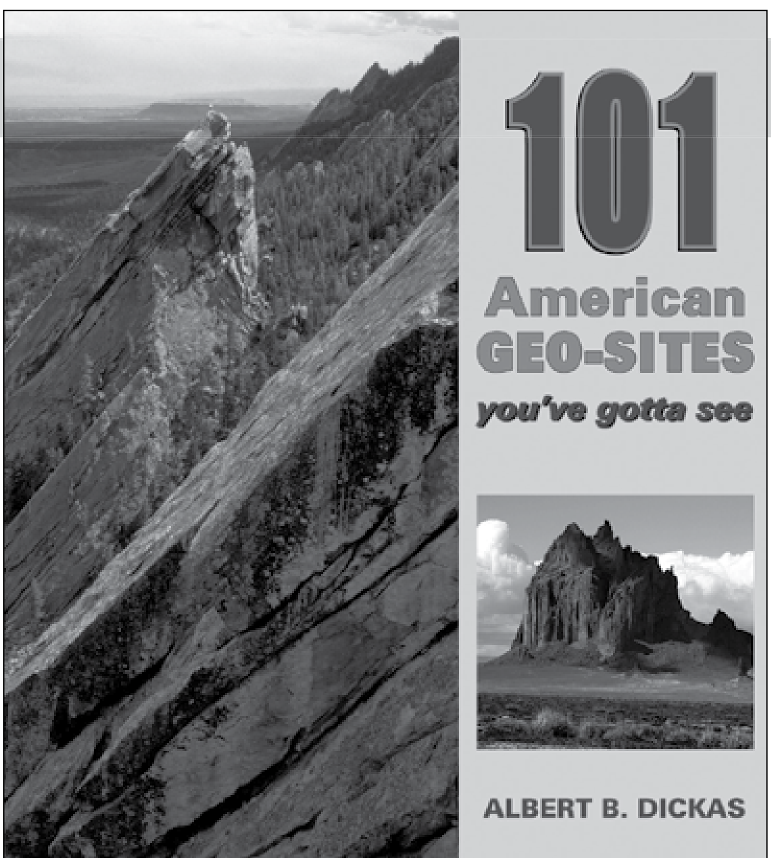

Todd Anthony Bianco

GSA is pleased to announce that Todd Anthony Bianco has been selected to serve as the 2012–2013 GSA-USGS Congressional Science Fellow. Bianco received a B.S. in physics at the University of Rhode Island (2001), where he was captain of the cross-country team and was also inducted into Phi Beta Kappa. Soon after graduation, he began work in the Mojave National Preserve, studying the local soundscape to assess the potential impacts of the proposed Ivanapah Valley Airport.

Bianco completed his M.S. (2004) and Ph.D. (2009) in Geology and Geophysics at the University of Hawaii at Mānoa. His research combines computational modeling of mantle dynamics and melting to make predictions about the volume and composition of lava erupted at volcano groups such as the Hawaiian and Galapagos Islands and Iceland. For his research efforts during his tenure at Hawaii, Bianco was selected as the 2007 ARCS Mānoa Chapter Scholar and was awarded a Maui High Performance Computing Center Grant. Bianco has also achieved success as a science communicator, having won best presentation awards at the 2006 and 2007 AGU fall meetings, as well as the 2007 Albert Tester Memorial Symposium. In his first postdoctoral appointment, Bianco researched the potential causes and patterns of volcanism in continental environments on a project funded by the Nevada Agency for Nuclear Projects. In 2010, he was awarded an NSF-EAR Postdoctoral Fellowship to expand his research on the fate of compositional heterogeneity in the mantle.

Bianco enjoys opportunities for education outreach. In 2007, he served as a science contributor and editor for a webpage that documented a seagoing expedition aboard the R/V *Kilo Moana* and led workshops and presentations related to the expedition at local schools. He also served as a visiting scientist in an NSF K–12 Program with Brown University.

As a Congressional Science Fellow, Bianco plans to rely on his experience with simplifying and scaling complicated systems and his ability to communicate scientific concepts to a wide range of audiences. Bianco relates that he is honored to serve as the 2012–2013 GSA-USGS Congressional Science Fellow and is humbled to follow in the footsteps of previous Fellows. He hopes to develop a credible and active voice for science, technology, and education policy during the fellowship year.



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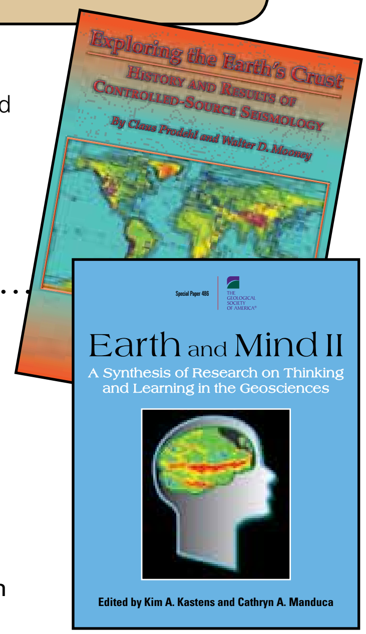

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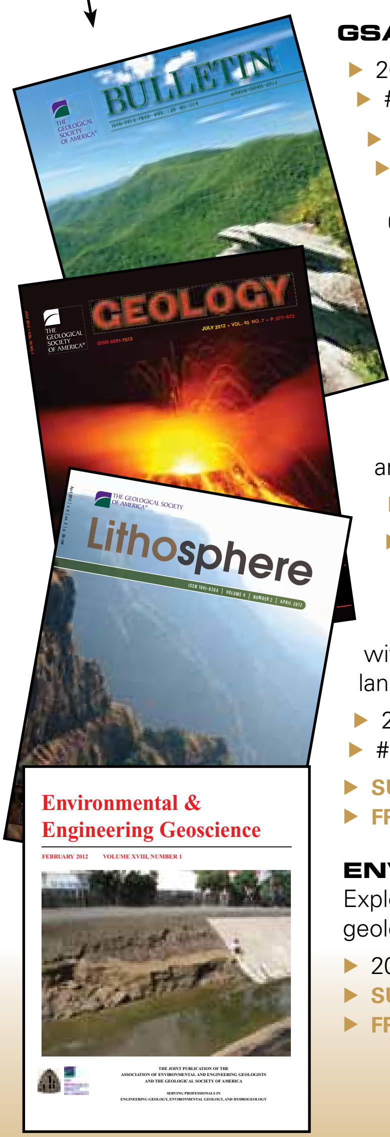

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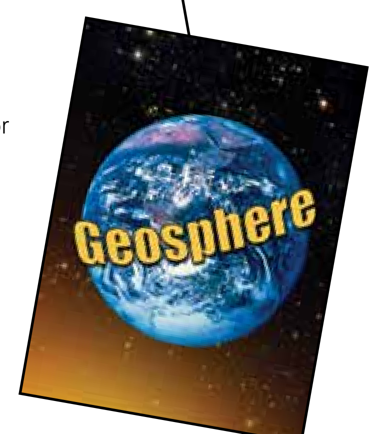

GEOSPHERE—Lets you branch out unfettered with free color and a chance to bring animations and interactivity to your papers.

- 2011 Impact Factor: 2.120 ▸ Five-Year Impact Factor: 2.651
- SUBMIT ONLINE: http://www.editorialmanager.com/geosphere
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LITHOSPHERE—A new kid on the block, but making its mark with popular papers on processes that affect the crust, upper mantle, landscapes, and sedimentary systems at all spatial and temporal scales.

- 2011 Impact Factor: 1.738 ▸ Five-Year Impact Factor: 1.738
- #11 ranked "geology" journal by ISI
- SUBMIT ONLINE: http://www.editorialmanager.com/lithosphere
- FREE SAMPLE ISSUE: http://lithosphere.geoscienceworld.org

ENVIRONMENTAL & ENGINEERING GEOSCIENCE
Explores issues relating to the interaction of people with hydrologic and geologic systems.

- 2011 Impact Factor: 0.340 ▸ Five-Year Impact Factor: 0.434
- SUBMIT ONLINE: http://eeg.allentrack.net/cgi-bin/main.plex
- FREE SAMPLE ISSUE: http://eeg.geoscienceworld.org

THE GEOLOGICAL SOCIETY OF AMERICA®

2012 AUGUST

www.gsapubs.org

Mentoring Tomorrow's Geoscience Leaders

The Geological Society of America (GSA) is proud to provide mentoring programs at all its meetings. At the Section Meetings, students are invited to participate in both the Roy J. Shlemon Mentor Program in Applied Geology and the John Mann Mentors in Applied Hydrogeology Program. These popular events, supported by the GSA Foundation through gifts from Roy J. Shlemon and John Mann, are designed to extend the mentoring reach of individual professionals from applied geology.

Mentors and students meet in a relaxing, informal setting, discussing applied geology or hydrogeology careers over a free lunch. The mentors, who come as volunteers, are professionals in these fields (check out the "Mentor Hall of Fame" at www.geosociety.org/mentors/hof.htm).

This spring, the Shlemon Program funds, in addition to financial assistance from the GSA Northeastern and Southeastern Sections, provided lunches and a place to converse to 450 students and 58 mentors; the Mann Program welcomed 174 students and 27 mentors. Both mentors and students leave these events expressing feelings of personal and professional growth. New friendships are made and professional contacts are established that will last well into the future.

GSA's Education & Outreach Program gratefully acknowledges the following mentors for their individual gifts of time and for sharing their insight with GSA's student members. To learn more about these programs, or to be a mentor in the future, please contact Jennifer Nocerino, jnocerino@geosociety.org.

The Roy J. Shlemon Mentor Program in Applied Geology

Helping Mentor Students Since 2000

SOUTH-CENTRAL SECTION

Jim Bones, Consultant
Todd Choban, Environeering Inc.
Dan Miggins, U.S. Geological Survey
David Scholl, U.S. Geological Survey
Chris Sumner, Lhoist North America
Robert Ward, Rio Grande Mining Co.

NORTHEASTERN SECTION

Marcel Belaval, EPA New England
Kevin Bohacs, ExxonMobil Exploration Co.
William Burton, U.S. Geological Survey
Julie Contino, American Museum of Natural History
Robert Cook, Cook Geologic
Charles Crocetti, Sanborn Head & Associates Inc.
Shane Csiki, New Hampshire Geological Survey
Mary DiGiacomo-Cohen, U.S. Geological Survey
John Dougherty, CDM Smith
Raymond Duchaine, ENVISION Inc.
Susan Halsey, Admiral Coastal Consulting
Lirim Hoxha, Empire Mining Albania
Bill Kelly, New York Geological Survey (ret.)
Jon Kim, Vermont Geological Survey
Jonathan Mead, Kleinfelder
Susan Price, Murphy Risk Services
Neil Rogers, Geological Survey of Canada
Laurie Scheuing, Hydrogeologist
Jeff Starn, U.S. Geological Survey
Bob Stewart Jr., ExxonMobil Exploration Co.
Marilyn Suiter, National Science Foundation
Margaret Thomas, Connecticut Geological Survey
Elaine Todd Trench, U.S. Geological Survey
Gregory Walsh, U.S. Geological Survey

CORDILLERAN SECTION

Edgar Angeles-Moreno, Fresnillo Plc.
German Bayona, Corporación Geológica ARES
Jonathan Glen, U.S. Geological Survey
Arturo Hernández Broca, Fresnillo Plc.
Margarita López Martínez, CICESE
Benito Noguez Alcántara, Fresnillo Plc.

SOUTHEASTERN SECTION

Jennifer Bauer, Appalachian Landslide Consultants PLLC
Robert Denton Jr., GeoConcepts Engineering Inc.
Richard Kolb, Duncklee & Dunham PC
Malcolm Schaeffer, HDR Engineering Inc.
Craig Sprinkle, CH2M HILL
Gerry Stirewalt, U.S. Nuclear Regulatory Commission
Frank Syms, Lettis Consultants International Inc.
Marianne Weaver, Retired Geologist
Paul Weaver, ESP Associates P.A.

NORTH-CENTRAL SECTION

Paul Doss, Consultant
Ralph Haefner, U.S. Geological Survey
Elizabeth Hardesty, Shell Appalachia
Laura Marshall, Ohio EPA
Terry Saarela, Huron-Manistee National Forests
David Saja, Cleveland Museum of Natural History
James Sams, Department of Energy

ROCKY MOUNTAIN SECTION

Scott Elrick, Illinois State Geological Survey
W. Payton Gardner, Sandia National Laboratories
John Hawley, Hawley Geomatters
Roberta Johnson, Freeport-McMoRan Copper & Gold
Jamey Jones, U.S. Geological Survey
Norbert Rempe, Consultant

2012 SOUTH-CENTRAL SECTION

The mouth of Santa Elena Canyon, Big Bend, Alpine, Texas. Credit: NPS/Dan Leavitt.

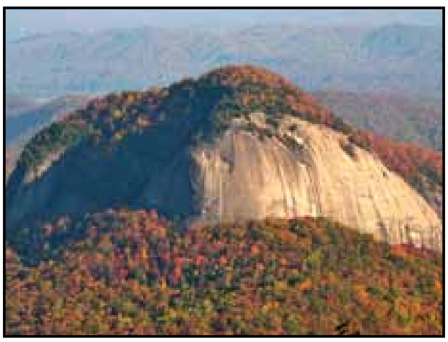
2012 NORTHEASTERN SECTION

Hartford riverfront. Photo courtesy of the Greater Hartford Convention & Visitors Bureau.

2012 CORDILLERAN SECTION

Green valley in the Sierra Gorda, located NE of Querétaro, México. Photo by Jesús Silva.

2012 SOUTHEASTERN SECTION



Looking Glass Rock. Photo courtesy Asheville Convention and Visitors Bureau.

2012 NORTH-CENTRAL SECTION

Covered bridge. Photo courtesy Dayton Montgomery County and Visitors Bureau.

2012 ROCKY MOUNTAIN SECTION

The Rio Grande in autumn. Credit: MarbleStreetStudio.com.

The John Mann Mentors in Applied Hydrogeology Program

Helping Mentor Students Since 2004

SOUTH-CENTRAL SECTION
Alfredo Granados-Olivas, Consultant
John Hawley, Hawley Geomatters
David Scholl, U.S. Geological Survey
Shirley Wade, Texas Water Development Board

NORTHEASTERN SECTION
Marcel Belaval, EPA New England
Robert Cook, Cook Geologic LLC
Raymond Duchaine, ENVISION Inc.
Susan Price, Murphy Risk Services
Rodney Sheets, U.S. Geological Survey
Stephen Urbanik, New Jersey Dept. of Environmental Protection

CORDILLERAN SECTION
Dave Colvin, Leonard Rice Engineers
Francisco Javier Gámez González, Comisión Nacional del Agua
Shaul Hurwitz, U.S. Geological Survey

SOUTHEASTERN SECTION
Peter Foster, Emery & Garrett Groundwater Inc.
Douglas Fraser, EEE Consulting Inc.
Wright Horton Jr., U.S. Geological Survey
Darren Lockhart, The EI Group Inc.
Craig Sprinkle, CH2M HILL

NORTH-CENTRAL SECTION
Sandra Eberts, U.S. Geological Survey
Jason Esselburn, Parsons Corporation
Brent Huntsman, Terran Corporation
Mike Proffitt, Ohio EPA Southwest District Office
Julie Schucker, CH2M HILL
Paul Stork, AMEC Environment & Infrastructure Inc.

ROCKY MOUNTAIN SECTION
Michael Barden, Geoscience Resources Inc.
Steven Silver, Balleau Groundwater Inc.
Maryann Wasiolek, Hydroscience Assoc. Inc.

THE GEOLOGICAL SOCIETY OF AMERICA®

Teacher Advocate Program (TAP)

"I walked away with knowing the relevance to implementing it into my curriculum."

Caves and Karst · Evolution in the Classroom · Earth Cycles · Climate Change throughout Earth History · Science & Technology of Gold · Nature of Science Talking Points · Rock Chart Poster · Geoscience Trivia · Deep Time · Cross Sections · Earthquakes · Weakened and Worn · Tsunamis · Landform Geology Paper Models · Volcanoes · Silicate Chemistry · Active Geology Models · Energy · Fossils · Forensic Geology · Plate Tectonics · What's in my Subaru? · Silicate Chemistry · EarthCaching

GSA Education & Outreach

"Great hands-on activities!"

Formally established in 2003, TAP aims to raise the number of teacher advocates for geoscience providing those teachers with (1) low-cost teaching resources, such as notes, materials (images, models, etc.), and useful classroom activities; (2) low-cost training opportunities for teachers on how to use TAP materials; (3) experiences in the field to provide teachers with more materials and insights.

TEACHER RESOURCES FROM GSA

Teachers say they would like to see additional resources on water, rocks and minerals, landslides and mass wasting, and glaciers. Many of the existing resources would also benefit from further development and updates so that they meet the new national standards and include information about recent events and cutting-edge research. Additionally, we would like to move from a CD format to an online delivery format. This will allow us to include technology such as apps, animations, and video clips into the resources. Additionally, an online format will make it easier to update the resources as new findings emerge.

"The activities for the students are interactive, interesting, and easy to understand."

TEACHER TRAINING SESSIONS

TAP provides training sessions at National Science Teachers Association (NSTA) meetings, both nationally and regionally, and some teacher conferences across the nation. The number of teachers who attend the TAP sessions is always high and in some cases (especially the national convention) overwhelming.

This year, TAP resumed teacher training sessions after a three-year hiatus. In March 2012, TAP was invited to participate in the annual GeoTech Conference in Dallas, Texas, USA. TAP presented three short courses on plate tectonics, minerals, and rocks. We estimate that 238 teachers and 13,598 students were impacted by this one conference.

FUTURE TAP TRAINING SESSIONS

- National Science Teachers Association Regional Conference: Louisville, Kentucky, USA: 18–19 Oct. 2012
- GSA's Annual Meeting: Charlotte, North Carolina, USA: 3 Nov. 2012
- Texas Science Teachers Conference (CAST): Corpus Christi, Texas, USA: 8–9 Nov. 2012
- Colorado Science Teachers Conference: Denver, Colorado, USA: 16 Nov. 2012
- National Science Teachers Association Regional Conference: Phoenix, Arizona, USA: 6–8 Dec. 2012
- National Science Teachers Association National Conference: San Antonio, Texas, USA: 11–14 April 2013

"I really enjoyed the content on minerals and the kid-proven ways to deliver instruction."

FIELD CAMPS AND GEOVENTURES FOR K–12 TEACHERS

Week-long teacher trips (called Teacher GeoVentures: www.geoventures.org) have operated every year since 2004. Trips have been run to Iceland, Hawaii, and the Galapagos Islands. GeoVentures participants leave with a renewed passion for teaching the geosciences and promoting geosciences within their schools and districts. There is no doubt that the teachers who have attended these trips have become the biggest advocates for earth science. It is vital that we expand the number of teachers who participate in field experiences so we can increase the number of teacher advocates for the geosciences.

In order to attract more teachers, TAP will begin to run teacher field camps in 2013. These field camps are designed to be shorter in duration, closer to home, and more affordable. The first field camp will take place in Colorado. It is our goal to have a field camp running in each of GSA's North American sections by 2015 in order to reach a larger group of teachers.

"Presenters were so knowledgeable and willing to go the extra mile!"

2013 FIELD CAMPS AND GEOVENTURES FOR K–12 TEACHERS

- GeoVenture: Ecuador and the Galapagos Islands: 4–14 June 2013
- Rocky Mountain Field Camp: 21–26 June 2013
- GeoVenture: Hawaii—Teachers and Families: 12–19 July 2013
- GeoVenture: Iceland: 30 July–5 August 2013

"I liked how you incorporated the labs, experiments, and activities into the lecture."

For more information, contact Davida Buehler at +1-303-357-1015 or dbuehler@geosociety.org.

www.facebook.com/GSAK12Education

www.geosociety.org/educate/tap.htm

THE GEOLOGICAL SOCIETY OF AMERICA®

P. Geoffrey Feiss, GSA Foundation President

SWITCH

Open pit coal mine in the Powder River Basin, Wyoming, USA. Photo by Harry Lynch.

"What is the most important issue of our time?" I can imagine a lot of "enthusiastic" conversations over coffee, beer, or the outcrop on this seemingly simple query. I have no idea which issue would win the argument, but I am sure that among the top three (two? one?) in any group of geoscientists would be energy. We have gotten here on fossil sunlight. But how will this world of 7,016,755,806 people (as of 30 May 2012 at 21:20 UTC according to the U.S. Census Bureau) find sufficient energy for the next 25, 50, 100 years without irreversible, on the human scale, damage to Earth?

Scott Tinker, director of the Texas Bureau of Economic Geology and Texas state geologist, has spent as much time as anyone thinking about this. Now, out of ten years of research and study, he has crafted (with ARCOS Films) the feature-length film *Switch*, a cinematic exploration of the world's energy resources. In the film, Tinker considers how we have arrived at our current energy mix and how to begin to chart a sustainable path to the future. Realistic, pragmatic, balanced, research-based—this film has the ability to change the public conversation from one based on fear, self-interest, or polemics to one based on facts and realities.

Tinker will be the 2012 GSA Michel Halbouty Lecturer at the GSA Annual Meeting in Charlotte, and attendees can see *Switch* for themselves. Or, you can go to **www.switchenergyproject.com** to view a trailer and learn about upcoming screenings near you.

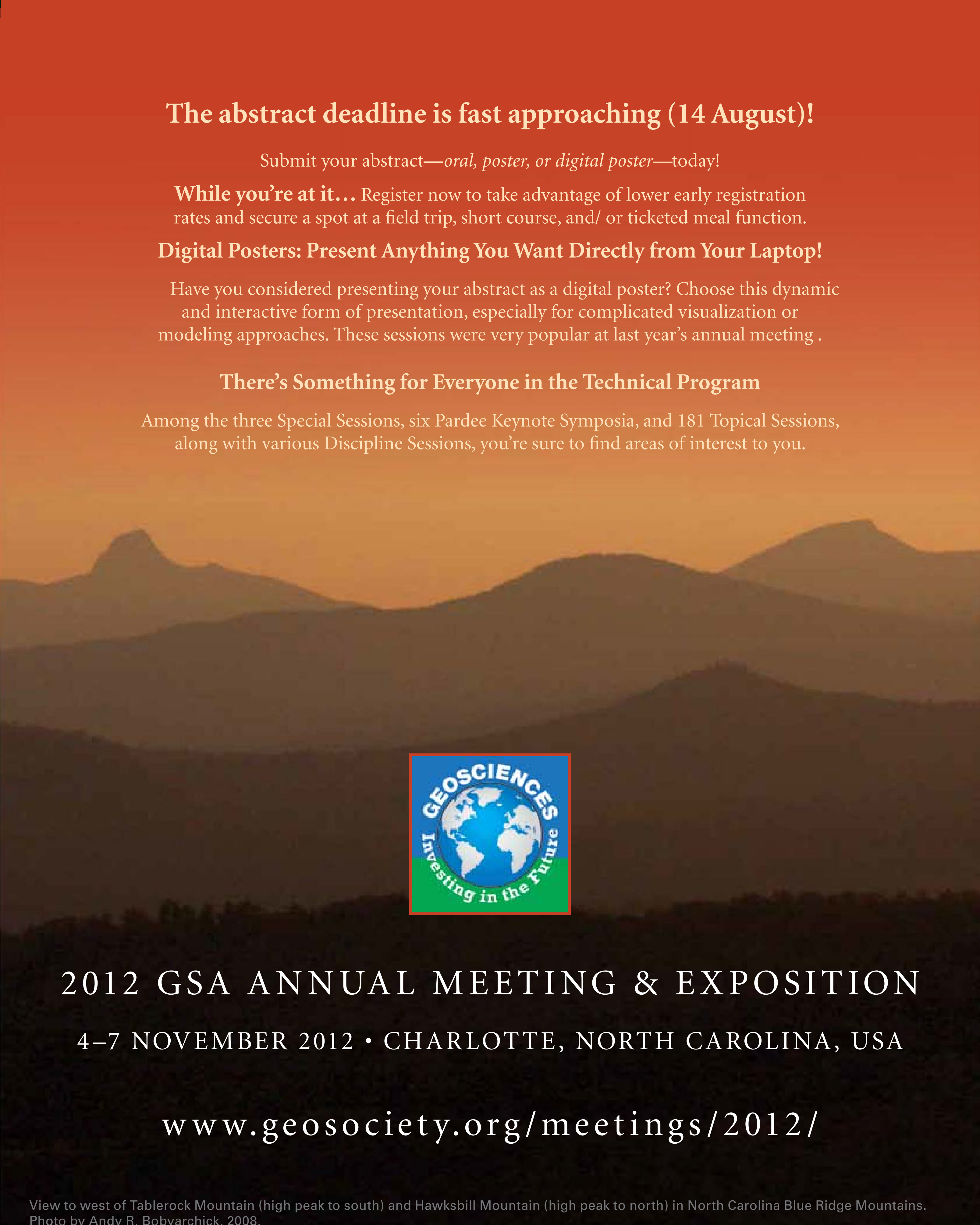
This is well and good, but how do we "push" this important message to a broader community—one that may not be predisposed to think about this issue and certainly not likely to go to a movie about energy?

GSA and the GSA Foundation, in collaboration with the Texas Bureau of Economic Geology, AGI, AAPG, The University of Texas at Austin, the Verizon Foundation, and the O'Donnell Foundation, are beginning an ambitious effort to use *Switch* as a means to initiate a national conversation about our energy future.

This fall, using GSA's campus representatives and others as our points of contact, we will screen this movie on some forty or more campuses across the country. Learning aids, curricular materials, and additional online resources will supplement viewings and discussions of the film. The hope is that the audience will not just be geoscience majors, though they are critical. We want to reach all scientists and engineers, as well as economics, business, and policy majors, environmental groups, and campus organizations dedicated to sustainability and conservation. In short, we would like *Switch* to catalyze a change in the way we all talk about, understand, and use energy.

A tall order. In the spring of 2013, with the partners described above, we will expand from 40 to another several hundred colleges and universities. Let us or your GSA Campus Rep (for a listing, see p. 44–49 of the July 2012 *GSA Today*) know if you would like to participate.

If you would like to make a contribution to the Foundation, please go to www.gsafweb.org/ or contact Anna Christensen, Chief Development Officer, GSA Foundation, +1-303-357-1007, achristensen@geosociety.org.



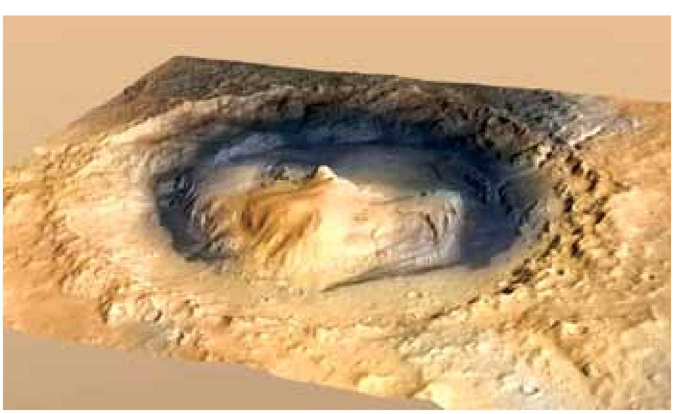
View to west of Tablerock Mountain (high peak to south) and Hawksbill Mountain (high peak to north) in North Carolina Blue Ridge Mountains. Photo by Andy R. Bobyarchick, 2008.

Pardee Keynote Symposia Highlights

Symposia are special sessions consisting of invited abstracts on innovative topics presented in a creative way. Six Pardee symposia will be presented at this year's meeting, and two are highlighted below (see the July *GSA Today* for the first in this series of highlights).

Artist rendering of the new Mars Rover, *Curiosity*. Image courtesy NASA.

P2. Mars Rover *Curiosity*: Geoscience in Gale Crater, Robert C. Anderson, convener. This session will provide an overview of Gale Crater and new insights on the major advances in understanding the geologic histories of Mars. *Cosponsored by GSA Planetary Geology Division.*



Gale Crater, Mars. Oblique view with vertical exaggeration. Image courtesy NASA/JPL-Caltech/ESA/DLR/FU Berlin/MSSS; www.nasa.gov/mission_pages/msl/multimedia/pia15101.html.

Sirmilik National Park, Baffin Island, Canada. The diverse geology in this park includes evidence of scouring by the Laurentide Ice Sheet. NASA image by Jeff Schmaltz, MODIS Rapid Response Team, 2 Oct. 2008; http://earthobservatory.nasa.gov/IOTD/view.php?id=35544.

P3. Meltwater Production from Source (Ice Margins) to Sink (Ocean); Magnitude, Chronology, and Significance, B. Brandon Curry and Eric C. Carson, conveners. By affecting terrestrial landscapes, oceans, and climate, ice sheets are key components of the Earth system. Meltwater is an important connection between terrestrial ice and the sea, and yet little is known regarding the timing and magnitude of large deglacial floods and their relevance to sea level change, sea surface temperature, and salinity. Talks in this symposium will address the current understanding of meltwater from source to sink, including ice margins, proglacial lakes, rivers, and oceans. We will focus on the last deglaciation of the Laurentide Ice Sheet and its effects on ocean salinity, surface temperature, and eustatic sea level. *Cosponsored by GSA Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division; American Quaternary Association (AMQUA).*

THE GEOLOGICAL SOCIETY OF AMERICA®

U.S. National Whitewater Center. Photo courtesy Visit Charlotte.

Come to Learn
Bring Your Family for Fun!

CHARLOTTE

Take advantage of your time in Charlotte to get out and explore with your kids or nurture your inner kid! Two sites you don't want to miss are the **U.S. National Whitewater Center** and **Discovery Place Science Museum.**

Paddle-boarding. Photo courtesy U.S. National Whitewater Center.

The **U.S. National Whitewater Center** is 15 minutes from Uptown Charlotte. At the USNWC, you and your children (4 years of age and older) can explore the newest craze of stand-up paddle boarding. You can also explore the Canopy Tour by zipping through the forested rim of the south ridge gorge (children age 10 to 14 must be accompanied by an adult). Kids of all ages can enjoy the Eco Trekking (based on geocaching) and a hike in the USNWC scenic trail system.

Little ones enjoying water fun; image courtesy Discovery Place.

Discovery Place is eight blocks from the Convention Center and is one of the leading hands-on science centers. Kids can discover daily programs with interactive exhibits, explosive experiments, and incredible shows in the IMAX® Dome Theater. Watch the GSA website for special opportunities at the Discovery Place for GSA Annual Meeting participants.

Speaking of the kids—GSA will again offer childcare services through KiddieCorp, with whom we've worked since 2005. This program provides meeting attendees with the opportunity to leave their children (6 months to 12 years old) with professionals who are solely dedicated to making them safe and happy. Attend sessions with peace of mind, knowing that your children are having fun with other children in a safe environment provided by one of the most successful childcare programs in the country. Register at **www.kiddiecorp.com/gsakids.htm** by **1 October.** The cost is US$7 per hour per child with a consecutive 2-hour minimum per child. At least one parent must be registered for the meeting.

Come to Learn
Make Time to Explore the Local (Brew) Scene!

Photo courtesy `Visit Charlotte.

CHARLOTTE

Charlotte has some great pubs that are not to be missed—many within walking distance of the convention center. Here's a taste of what to expect:

- **Carolina Ale House** is located just one and a half blocks from the convention center. Enjoy great food and an endless selection of draft microbrews while watching the sporting event of your choice!
- **The Dandelion Market** offers a full bar and nearly two dozen craft beers. This venue takes its name from a famous outdoor market that thrived in Dublin in the early 1970s.
- **Connolly's on Fifth**—To continue your search for the perfect pint, stop by Connolly's and catch up with friends while enjoying one of the largest outdoor patios in Charlotte. Take advantage of the outdoor TVs to watch a game, or play a friendly game of ping pong!
- **Rí Rá Irish Pub** has a second-level patio overlooking Hearst Plaza in the middle of downtown Charlotte. Rí Rá was named "Best Pub" on *Charlotte Magazine*'s 2011 Best of the Best list.
- **EpiCenter**—If you want entertainment to go along with your patio and pub experience check out Charlotte's EpiCenter, which is within walking distance from the Charlotte Convention Center and a convenient stop on the LYNX Blue Line (light rail).
- **Flemming's Prime Steak House & Wine Bar** also offers a unique selection of craft beers.
- **BlackFinn American Saloon** has a lot of options, including two outdoor patios, a salon, and a pub. The patios provide the most sought after seating at BlackFinn, along with views of the EpiCenter and Uptown Charlotte. The pub at BlackFinn is located on the first floor, and the salon is on the second floor with dozens of TVs for the ultimate sports-watching location.

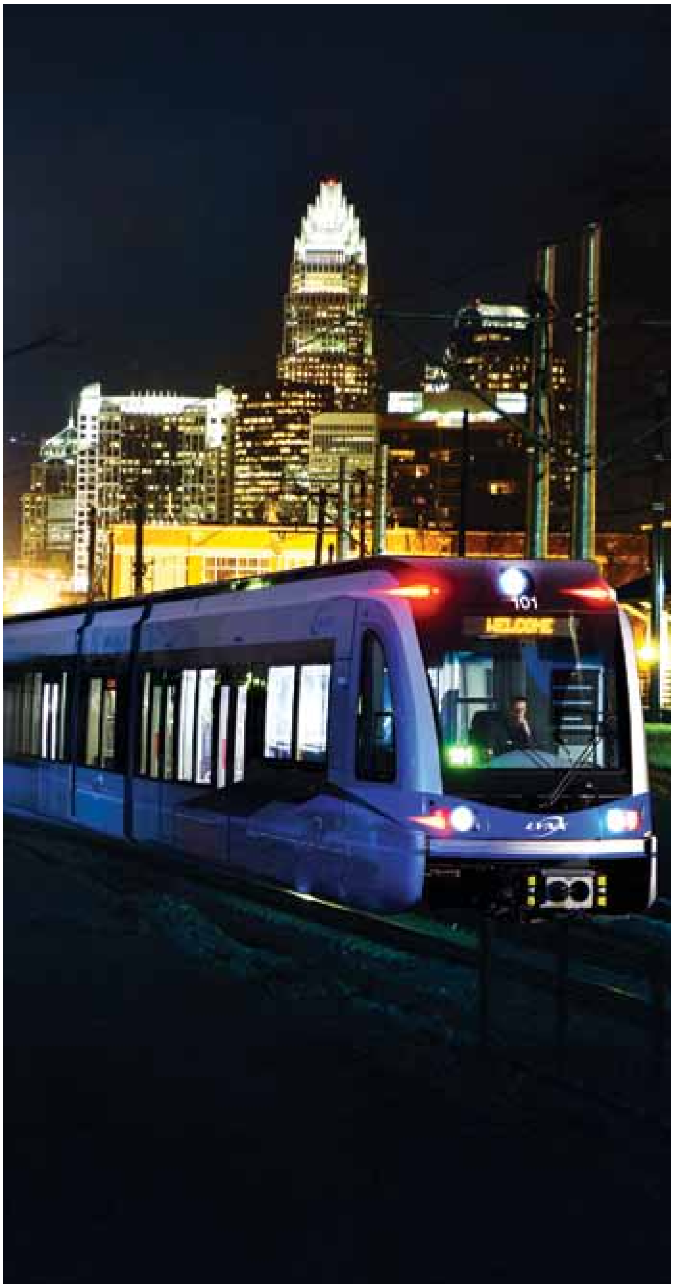


Photo courtesy Visit Charlotte.

Classified Rates—2012

Ads (or cancellations) must reach the GSA advertising office no later than the first of the month, one month prior to the issue in which they are to be published. Contact advertising@geosociety.org, +1.800.472.1988 ext. 1053, or +1.303.357.1053. All correspondence must include complete contact information, including e-mail and mailing addresses. To estimate cost, count 54 characters per line, including punctuation and spaces. Actual cost may differ if you use capitals, boldface type, or special characters. Rates are in U.S. dollars.

Classification	Per Line for 1st month	Per line each addt'l month (same ad)
Positions Open	$8.95	$8.70
Fellowship Opportunities	$8.95	$8.70
Opportunities for Students		
First 25 lines	$0.00	$4.75
Additional lines	$4.75	$4.75

Positions Open

GEOCHEMISTRY
TENURE-TRACK ASSISTANT PROFESSOR
DEPT. OF GEOLOGICAL SCIENCES
UNIVERSITY OF DELAWARE

The University of Delaware has a great tradition of excellence, from our founding as a small private academy in 1743 to the research-intensive, technologically advanced institution of today. UD is a Land Grant, Sea Grant, and Space Grant institution. The Carnegie Foundation for the Advancement of Teaching classifies UD as a research university with very high research activity—a designation accorded fewer than 3% percent of U.S. colleges and universities. Located in scenic Newark, Delaware, within two hours of New York, Philadelphia, Baltimore, and Washington, D.C., the university is a state-assisted, privately governed institution.

The Dept. of Geological Sciences invites applications for a full-time, tenure-track Assistant Professor position in geochemistry beginning Fall 2013. Areas of interest include, but are not limited to, environmental geochemistry, hydrogeochemistry, geochronology, biogeochemistry, paleoclimatology, petrology, and geochemical modeling.

The successful candidate is expected to build an externally funded, innovative research program, to be committed to effective teaching at the undergraduate and graduate level, and to contribute to the academic life of the department and University. We seek a colleague who will complement and build on the existing strengths in geoscience within the department and across the University.

The Dept. of Geological Sciences resides in the College of Earth, Ocean, and Environment (CEOE) and is part of a broad geoscience community at the University of Delaware. CEOE includes the Delaware Geological Survey, the School of Marine Science and Policy, and the Depts. of Geological Sciences and of Geography. The University's current strategic plan calls for expanding research across campus in the areas of environment and energy; opportunities therefore exist for collaboration between faculty across the University's seven colleges and for work within the auspices of the Delaware Environmental Institute (DENIN), the UD Energy Institute, and the Delaware Biotechnology Institute. More information about the department and geoscience work and resources at the University of Delaware can be found at www.geosci.udel.edu/geochemistry/.

A Ph.D. at time of appointment is required. Candidates should submit a cover letter describing their research and teaching interests and experience, a curriculum vitae, and the names and contact information for three references as one document through the online UD application system at www.udel.edu/udjobs/. Questions about this position can be directed to the chair of the Geochemistry Search Committee, Dr. Sue McGeary (smcgeary@udel.edu). Review of applications will begin on 1 Sept. 2012, and will continue until the position is filled.

The UNIVERSITY OF DELAWARE is an Equal Opportunity Employer.

LSU
LOUISIANA STATE UNIVERSITY

ASSISTANT PROFESSOR PROFESSIONAL PRACTICE
(FIELD CAMP DIRECTOR AND INSTRUCTOR)
DEPARTMENT OF GEOLOGY AND GEOPHYSICS

The Department of Geology and Geophysics at Louisiana State University has an opening for an Assistant Professor – Professional Practice. During the academic year, the position is designed to be 50% teaching, 25% coordinating content and supervising introductory laboratory courses, and 25% field camp director duties. The teaching load is 3 courses per semester and can include introductory geology courses, a course specifically designed for Petroleum Engineering majors, and possibly a course for geology majors in your specialty. Additionally, supervising the graduate assistants who are teaching the introductory physical and historical geology laboratory courses is also required. LSU G&G offers two field camp programs – one for upper-level undergraduate students (senior camp) and one for inbound freshmen geology majors (freshmen camp). Field camp director duties include preparation for the field camp season, recruiting students for freshmen field camp, hiring the instructor for the freshmen field camp, hiring the kitchen staff, and managing the field camp budgets.

During the summer, the position is 100% Field Camp Director. A position that includes teaching the 6-credit hour field camp course that is a required course for BS majors, supervising the instructor of the Freshmen Field Camp and the graduate teaching assistants assigned to both courses, and directing the overall field camp programs. **Required Qualifications:** Ph.D. in Geology or a related field. An offer of employment is contingent on a satisfactory pre-employment background check. Application deadline is September 14, 2012 or until candidate is selected. Apply online and view a more detailed ad at: **www.lsusystemcareers.lsu.edu. Position #028085**

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WILLIAM E. WHITE POSTDOCTORAL
SCHOLARSHIP IN GEOLOGICAL SCIENCES
AND GEOLOGICAL ENGINEERING
QUEEN'S UNIVERSITY AT KINGSTON
ONTARIO, CANADA

The Dept. of Geological Sciences and Geological Engineering of Queen's University, one of Canada's premier earth-science departments, invites applications for its William E. White Postdoctoral Scholarship, created from a fund endowed by the estate of William E. White. The award will be made for one year and may be renewed for a second year. The annual stipend will be no less than $50,000.

The William E. White Postdoctoral Scholarship will be awarded to an outstanding scientist who has completed the Ph.D. degree, normally within the two-year period preceding the time of the appointment. The area of research is open, but the scholar's research must be complementary to that being pursued in the Dept. of Geological Sciences and Geological Engineering. The research program to be undertaken and the level of support of research costs and moving expenses will be negotiated with a faculty member at the time the award is made. Potential applicants may obtain an outline of current research interests on the departmental website, www.queensu.ca/geol/, and are strongly encouraged to initiate contact with a potential faculty supervisor in advance of applying. Fit with the research interests of the department and the research excellence of the candidate will be the primary considerations in the selection process.

The department invites applications from all qualified individuals. Queen's University is committed to employment equity and diversity in the workplace and welcomes applications from women, visible minorities, aboriginal people, persons with disabilities, and persons of any sexual orientation or gender identity.

Applicants should send a curriculum vitae, a statement of research interests, and samples of research writing to the following address. Applicants should contact their referees and arrange for at least three confidential letters of reference to be sent to the address below. Review of complete applications will begin on 30 Sept. 2012.

Professor D. Jean Hutchinson, Dept. Head, Dept. of Geological Sciences and Geological Engineering, Queen's University, Kingston, Ontario, Canada, K7L 3N6, Fax: 613-533-6592, hyde@geol.queensu.ca.

GEOCHEMISTRY, PETROLOGY AND MINERAL RESOURCES, UNIVERSITY OF ARIZONA

The Dept. of Geosciences at the University of Arizona seeks to hire a tenure-track faculty member at the Assistant or Associate Professor level with a commitment to interdisciplinary work in the general area of mineral resources. The position has been created as part of a campus-wide initiative on the sustainability of mineral resources. The successful candidate is expected to actively engage in multidisciplinary research and teaching through the Dept. of Geosciences, the School of Earth and Environmental Sciences, the partnerships and initiatives of the Lowell Institute for Mineral Resources, and related professional programs. Areas of interest are very broad, and examples include fluids in crustal processes, geothermal or active magmatic or metamorphic systems, isotope geochemistry or petrology, or biogeochemistry of metal systems. Approaches can be field, lab, or theoretical and could involve settings from surficial to magmatic, scales from microscopic to global, topics from basic science to applications and policy. The department is seeking an individual who is able to work with diverse students and colleagues. The candidate's research should be original and address significant geological and/or geochemical questions. Apply to UA Job Number 50151, www.hr.arizona.edu/jobs; review of applications will begin on 15 Sept. and continue until the search is completed. In addition to a cover letter, CV, and statement of teaching and research interests, please submit (preferably by e-mail) up to five reprints of published work and provide the names and contact information for at least three references to gpersearch@email.arizona.edu or by mail to The GPER Search Committee, Dept. of Geosciences, University of Arizona, Tucson, AZ 85721-0077, USA.

TWO POSITIONS: SEDIMENTARY PROCESSES AND GLOBAL CHANGE SCIENTIST/ ENVIRONMENTAL BIOGEOCHEMIST, DEPT. OF EARTH AND ENVIRONMENTAL SCIENCES, BOSTON COLLEGE

The Dept. of Earth and Environmental Sciences at Boston College invites applications for two Earth Systems Scientists to start in Fall 2013.

Sedimentary Processes. This is a tenure-track position expected to be made at the Assistant Professor level. Areas of expertise might include (but are not limited to) basin analysis, reflection seismology, sediment transport, and biogeochemical processes in sedimentary systems. The successful candidate will be expected to develop a vigorous externally funded research program integrated with excellence in teaching within the geological sciences and environmental geoscience curriculum at both the undergraduate and graduate levels, including teaching courses in sedimentology and stratigraphy for majors.

Global Change Scientist/Environmental Biogeochemist. Areas of expertise might include (but are not limited to) elemental cycling and associated climate feedbacks, organic geochemistry of marine, freshwater and soil environments, and coupled hydrogeomorphic-ecosystem response to natural and human-caused change and disturbance. The successful candidate will be expected to develop a vigorous externally funded research program integrated with excellence in teaching within the earth and environmental geoscience curriculum at both the undergraduate and graduate levels, including teaching introductory courses in climate change and upper level electives in the area of the successful candidate's expertise. Applicants at all experience levels will be considered. A successful candidate at the associate or full professor level will be expected to participate in development of interdisciplinary environmental programs.

Information on the department, its faculty and research strengths can be viewed at **www.bc.edu/eesciences**. Applicants should send a curriculum vita, statements of teaching and research interests, and the names and contact information of at least three references as a single PDF-file e-mail attachment to either sedpos@bc.edu or globalchangepos@bc.edu. Review of applications will begin on 12 Nov. 2012. Department faculty will be available at the GSA and AGU fall meetings to meet with applicants. Boston College is an academic community whose doors are open to all students and employees without regard to race, religion, age, sex, marital or parental status, national origin, veteran status, or handicap.

TENURE-TRACK FACULTY POSITION APPLIED GEOPHYSICS, DEPT. OF GEOLOGICAL SCIENCES AND GEOLOGICAL ENGINEERING, QUEEN'S UNIVERSITY

The Dept. of Geological Sciences and Geological Engineering at Queen's University, which has a long history of excellence in undergraduate and graduate education and world class research, is seeking individuals with outstanding research and teaching capabilities for a tenure-track position at either the Assistant or Associate Professor in Applied Geophysics to begin on 1 Jan. 2013 or 1 July 2013. The successful candidate will be a Professional Engineer, or will be eligible to apply for Professional Engineering status immediately, by virtue of having graduated from an accredited engineering program. The candidate will build on the existing applied geophysics specialization stream in the Geological Engineering program, and may also teach students from Geological Sciences and other departments at Queen's. Demonstrated excellence in teaching and field investigation in a variety of geophysical techniques, data analysis, and interpretation will be an asset. The candidate is expected to carry on an active, externally funded research program of international caliber and to supervise graduate students at the M.Sc. and Ph.D. levels. A willingness to engage in collaborative research with departmental colleagues will also be considered in the selection process. For more information about faculty research interests, the full range of undergraduate and graduate teaching programs, and our laboratory facilities, visit www.geol.queensu.ca.

The University invites applications from all qualified individuals. Queen's University is committed to employment equity and diversity in the workplace and welcomes applications from women, visible minorities, aboriginal people, persons with disabilities, and persons of any sexual orientation or gender identity. All qualified candidates are encouraged to apply; however, Canadians and permanent residents will be given priority.

Academic professionals at Queen's University are governed by the Collective Agreement between the Queen's University Faculty Association (QUFA) and the University, which is posted at www.queensu.ca/provost/faculty/facultyrelations/qufa/collectiveagreement.html. Remuneration will be in accordance with the Collective Agreement, which considers qualifications and experience.

Applications should include a complete and current curriculum vitae, letters of reference from three (3) referees of high standing, a statement of teaching experience, a statement of research interests and future plans, and samples of research writing. **Please arrange to have applications and supporting letters sent directly to** Dr. D.J. Hutchinson, Head, Dept. of Geological Sciences and Geological Engineering, Queen's University, Room 240 Bruce Wing, Kingston. Ontario K7L 3N6, Canada, adminassistant@geol.queensu.ca

Applications will be accepted until 31 August 2012, or until a suitable candidate is identified. Review of applications will commence shortly thereafter, and the final appointment is subject to budgetary approval.

FACULTY POSITIONS IN AQUEOUS/LOW-TEMPERATURE GEOCHEMISTRY GEOCHRONOLOGY, AND GLOBAL CLIMATE CHANGE AT THE UNIVERSITY OF MICHIGAN

The Dept. of Earth and Environmental Sciences at the University of Michigan is searching for tenure-track faculty candidates for a university-year appointment in the areas of Aqueous/Low-Temperature Geochemistry, Geochronology, and Global Climate Change, starting September 2013. Appointments at the assistant professor level are preferred, but exceptional candidates at higher levels will be considered. We encourage applications from candidates with records of research and teaching in any one of these areas.

Successful candidates are expected to establish an independent research program and contribute to both undergraduate and graduate teaching in a large public university. Candidates whose research and teaching complement and enhance the existing programs in the Dept. of Earth and Environmental Sciences will receive special consideration. Applicants must have a Ph.D. and should submit a CV, statement of current and future research plans, statement of teaching philosophy and experience, and contact information for at least four persons who can provide letters of recommendation.

Further information about the department and the positions can be found at www.lsa.umich.edu/earth. To apply, please go to www.earth.lsa.umich.edu/facultysearch/newapplicant, complete the online form, and upload the required application documents as a single PDF file. If you have any questions or comments, please send an email message to earth-search@umich.edu.

The application deadline is 24 Sept. 2012 for full consideration, but applications will continue to be reviewed until the position is filled. Women and minorities are encouraged to apply. The University is supportive of the needs of dual career couples. The University of Michigan is an equal opportunity/affirmative action employer.

TWO TENURE-TRACK FACULTY POSITIONS DEPT. OF EARTH SCIENCES UNIVERSITY OF MINNESOTA

We invite applications for two tenure-track faculty positions at the Assistant Professor level, one in the general area of Earth Surface Processes and one in the general area of Hydrogeologic Processes. We are seeking colleagues who will build innovative research programs and complement and extend our research and teaching strengths.

Areas of focus for the Earth Surface Processes position could include physical, chemical, and/or biological aspects of Earth-surface dynamics and evolution; for example, interactions of tectonic, glacial, and/or coastal systems with landscapes; research on changing surface environmental conditions and their causes in modern or ancient systems; critical zone processes; planetary surface dynamics; natural hazards; surface response to climate change; or near-surface processes associated with energy, mineral, and water resources.

Areas of focus for the Hydrogeologic Processes position could include physical, chemical, and/or biological aspects of groundwater geology; for example, groundwater, solute, and/or energy transfer dynamics; groundwater-lake-surface water interactions; environmental hydrogeology; groundwater and climate change; connections between hydrogeologic processes and tectonics, seismicity, landscape evolution, ore genesis; role of groundwater in biological and/or geochemical cycles; or life in extreme environments.

Successful candidates will teach courses in their fields of expertise at the undergraduate and graduate levels and will participate in the breadth of instruction in our curriculum; see www.esci.umn.edu/dept/students/.

The Dept. of Earth Sciences is part of the N.H. Winchell School of Earth Sciences, which also hosts NSF-funded research centers (the National Lacustrine Core Repository; the National Center for Earth-Surface Dynamics; and the Institute for Rock Magnetism) and includes the Limnological Research Center, the Minnesota Geological Survey, and the Polar Geospatial Center. College and University resources include St Anthony Falls Laboratory, Institute on the Environment, Materials Characterization Facility, Supercomputer Institute, and Digital Technology Center. Further information concerning the department and School of Earth Sciences is at www.esci.umn.edu.

Appointment could begin as early as summer 2013. A Ph.D. must be earned by the time of appointment. Review of applications will begin 4 Sept. 2012 and will continue until an appointment is made.

All candidates must complete an online application via the University of Minnesota employment system at **https://employment.umn.edu** (requisition numbers 178172 for Earth Surface, 178199 for Hydrogeology). The application includes (1) a curriculum vitae that includes a complete list of publications, (2) a statement of research interests, (3) a statement of teaching interests, and (4) names, addresses and e-mail addresses of at least three references. Questions about these positions can be directed to Professor Katsumi Matsumoto, katsumi@umn.edu (Earth Surface Processes) and Professor William Seyfried, wes@umn.edu (Hydrogeologic Processes).

The University of Minnesota is committed to the policy that all persons shall have equal access to its programs, facilities, and employment without regard to race, color, religion, national origin, sex, age, marital status, disability, public assistance status, veteran status or sexual orientation.

FIELD GEOLOGIST/PETROLOGIST
CALIFORNIA UNIVERSITY OF PENNSYLVANIA

California University of Pennsylvania invites applications for this tenure-track faculty position, Dept. of Earth Sciences; Ph.D. in Geology or related field is required, demonstrated experience in undergraduate education and a willingness to teach a broad spectrum of courses. Candidate will be an outstanding educator who can integrate classroom, technology, field and laboratory approaches to teaching geosciences. Candidates must demonstrate experience working with diverse populations.

For position details and to apply, visit https://careers.calu.edu.

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The Kentucky Geological Survey at the University of Kentucky is seeking a candidate to lead the Water Resources Section as head and senior scientist. They will direct research and supervise staff. The Section conducts groundwater research in a variety of geologic settings, maintains the Kentucky Groundwater Data Repository, and participates in the Kentucky Groundwater Monitoring Network.

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GROUNDWORK

Furthering the Influence of Earth Science

Updating the Debate on Model Complexity

Craig T. Simmons, *National Centre for Groundwater Research and Training, Flinders University, Adelaide SA, Australia; and* ***Randall J. Hunt,*** *U.S. Geological Survey, 8505 Research Way, Middleton, Wisconsin 53562, USA, rjhunt@usgs.gov.*

As scientists who are trying to understand a complex natural world that cannot be fully characterized in the field, how can we best inform the society in which we live? This founding context was addressed in a special session, "Complexity in Modeling: How Much is Too Much?" convened at the 2011 Geological Society of America Annual Meeting. The session had a variety of thought-provoking presentations—ranging from philosophy to cost-benefit analyses—and provided some areas of broad agreement that were not evident in discussions of the topic in 1998 (Hunt and Zheng, 1999). The session began with a short introduction during which model complexity was framed borrowing from an economic concept, the Law of Diminishing Returns, and an example of enjoyment derived by eating ice cream. Initially, there is increasing satisfaction gained from eating more ice cream, to a point where the gain in satisfaction starts to decrease, ending at a point when the eater sees *no* value in eating more ice cream. A traditional view of model complexity is similar—understanding gained from modeling can actually decrease if models become unnecessarily complex. However, oversimplified models—those that omit important aspects of the problem needed to make a good prediction—can also limit and confound our understanding. Thus, the goal of all modeling is to find the "sweet spot" of model sophistication—regardless of whether complexity was added sequentially to an overly simple model or collapsed from an initial highly parameterized framework that uses mathematics and statistics to attain an optimum (e.g., Hunt et al., 2007). Thus, holistic parsimony is attained, incorporating "as simple as possible," as well as the equally important corollary "but no simpler."

Complexity will not go away simply by fiat; too many problems require complexity to adequately address societal needs and expectations. In recognition of the need to at times live in a complex world, Anne-Sophie Høyer discussed a new capability to tune 3-D geological modeling for water resource problems (Høyer et al., 2011). Lars Nebel followed with a demonstration of manual and semi-automated ways to manipulate voxel (short for *volume element*, analogue to a 2-D pixel) modeling of complex geology (Nebel et al., 2011). The visualization and investigation of possible realizations can appreciably influence end products such as hydrological models. Hunt's presentation showed models that seem like "big hammers" but fall short in predictive capability because data number and type available were not sufficient to constrain processes important for the prediction of interest (Hunt and Walker, 2011). Although Hunt's example focused on coupled groundwater–surface water modeling, imperfect characterizations of uncertainty can be expected in any modeling endeavor that relies on limited observations to constrain complex and highly parameterized processes.

Complexity needs can be expected to change over time as well, owing to changes in system properties and societal objectives. Denis Peach addressed the complexity resulting from the societal need for a holistic basin-scale integrated model of the River Thames in the UK (Hughes et al., 2011). The basin is characterized by a wide variety of bedrock and sediments that may not be in hydrologic connection even if proximal in location. The river is also actively managed. Rather than putting all eggs in one basket, flexibility is built in from the beginning, as underscored by a reliance on an open standard for linking current and future models.

Henk Haitjema also emphasized the need for flexibility as one looks to find not "true" or "optimal" but "adequate" complexity—where adequate is derived from the societally relevant topic of cost-benefit analysis (Haitjema, 2011). That is, if 80% of the answer can be obtained with 10% of the work, might that be enough to sufficiently answer the question? Haitjema suggested an approach relying on very simple conceptualizations and calculations that are progressively extended until an adequate depiction of the system is reached. However, no one is born knowing how to add all necessary complexity for all problems. Therefore, Haitjema also underscored an associated inherent need of efficient stepwise modeling: heightened development of intuition and hydrosense. Making this insight a primary objective of professional development will assist all modeling endeavors regardless of relative simplicity or complexity.

Fred Molz expanded the philosophical underpinnings of model complexity with an example of "computer-aided thinking." This term suggests a utility for models even if mathematical chaos violates the concept of a single unique reality or where a premise of classic model prediction fails (Molz et al., 2011). Molz described a number of analyses performed to explain plutonium transport in field lysimeters, starting with steady-state, then transient soil-water movement. Simulations included geochemical reactions that account for changes in mobility due to oxidized and reduced conditions. Further extensions to the conceptual model were needed, culminating with plant models and lab experiments of plant transport pathways unknown at the beginning. This work accentuated the place of models in the scientific method and how various hypotheses are formalized and tested. Moreover, Molz demonstrated the importance of interdisciplinary thinking for

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today's problems: No matter how sophisticated the representation of soil water movement and abiotic geochemistry, field results could not be duplicated. The field results were only simulated after including movement via plant transport. This underscores potential ecohydrological drivers of many of today's seemingly abiotic problems.

Daniel Abrams compared end-extremes of the complexity-simplicity scale, where insights gained from intensive particle tracking from a 3-D groundwater flow model were also obtained using a simple exponential solution for predictions of watershed-scale transit time distributions (Abrams and Haitjema, 2011). The exponential formulation was also extended to watershed-scale nitrate transit time distributions. These simple conceptualizations are vital for quickly assessing the effects of actions over very large watershed scales—for example, the relation of Upper Mississippi nitrate transport to societally important hypoxia in the Gulf of Mexico. Jeff Starn presented a case in which overly simplistic conceptualizations limited the usefulness of tritium tracer data to investigate drivers of changing water quality (Starn and Green, 2011). However, rather than simply moving to an overly complex model, his work demonstrated a middle ground for complexity and simplicity, one that recognizes the potential artifacts of large model grids but addresses the issue with additional simple methods. Philip Brunner also demonstrated the sliding scale nature of the complexity versus simplicity issue—in some cases, good predictions can be had, not because all parameters were accurately estimated, but because only certain combinations of these parameters were sufficiently accurate (Brunner et al., 2011). Thus, it is possible that a model's predictive power may lose little if it were simplified appropriately.

John Doherty highlighted a need to move beyond the "either/or" framing of the complexity/simplicity question (Doherty, 2011). He cautioned against expectations of widespread utility from any single model conceptualization given an unknowably complex world and today's multifaceted decision making. Often the best model use is to represent the uncertainty in a model prediction, reduce that uncertainty to the extent possible given the available field data, and provide these critical outputs at the speed of real-world decision making.

Chunmiao Zheng offered a succinct summary on his experiences using very simple models for regulatory decision making and extremely complex models and very large field data collection to elucidate salient processes to better understand and define salient simplicity (Zheng, 2011). He took issue with a focus on models being too complex or too simple. The focus instead should be, is the model "good" or "bad"? If we recognize all models are a simplification of reality but have different objectives, some are necessarily more complex than others. The optimal level of complexity for any model should be dictated by its purpose. Such a pragmatic handling of the overarching topic recognizes both the underlying scientific issues of non-uniqueness as well as the societal realm in which most models are consumed. Given that all models should be constructed for a reason, the model objective becomes the primary prism for any and all discussions of model complexity.

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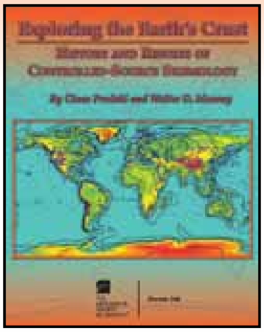

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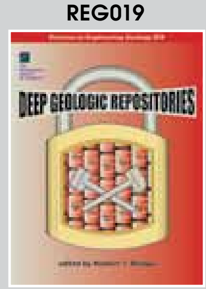

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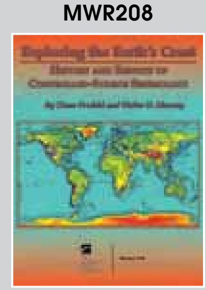

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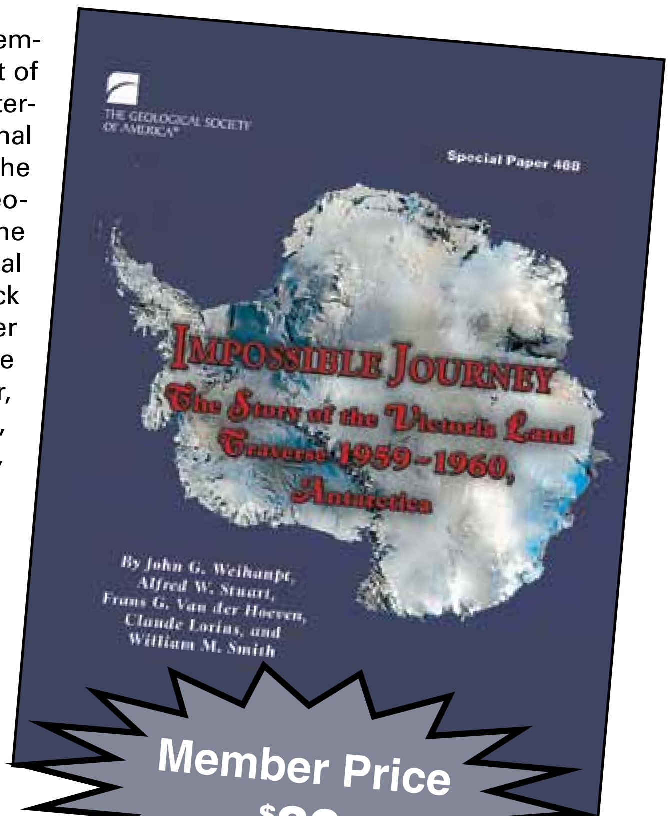

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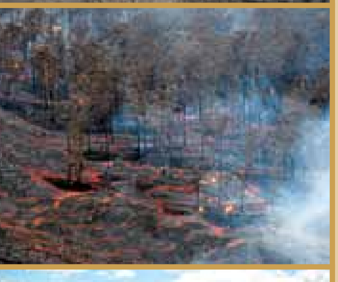


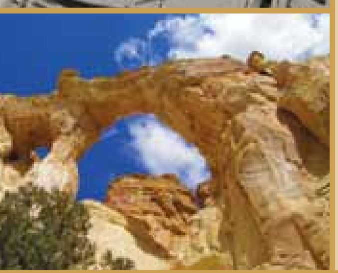

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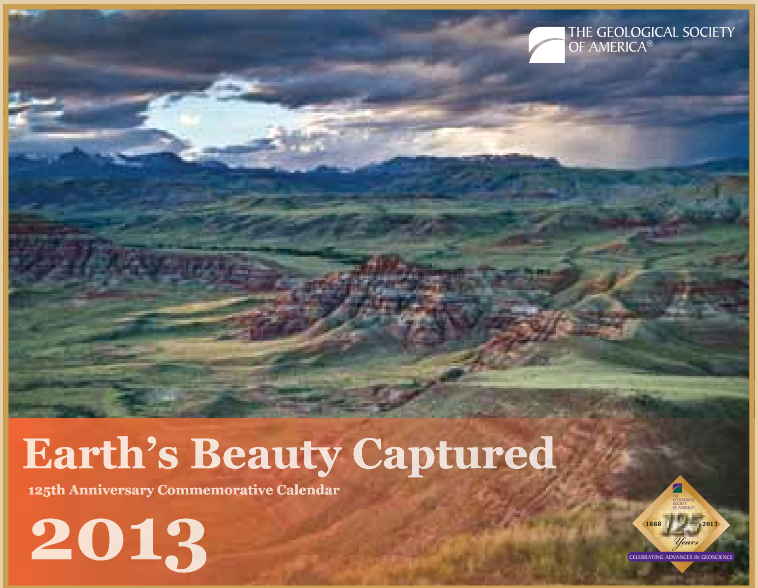
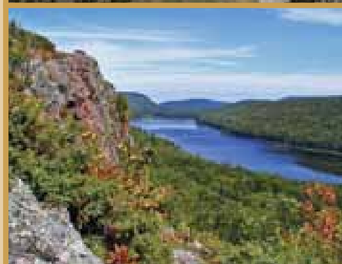
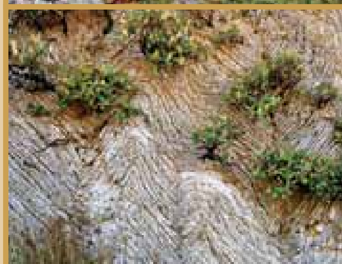
CAL2013, 11" × 14" calendar | **$9.95** (sorry, no additional discount)



SPECIAL FEATURES

- Dates of many noteworthy eruptions and earthquakes
- Monthly QR codes that link to a FREE version of 12 GSA articles of interest
- Birthdates of famous geoscientists
- Calendar of 2013 GSA events, meetings, and deadlines
- Timeline of important events in GSA history



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