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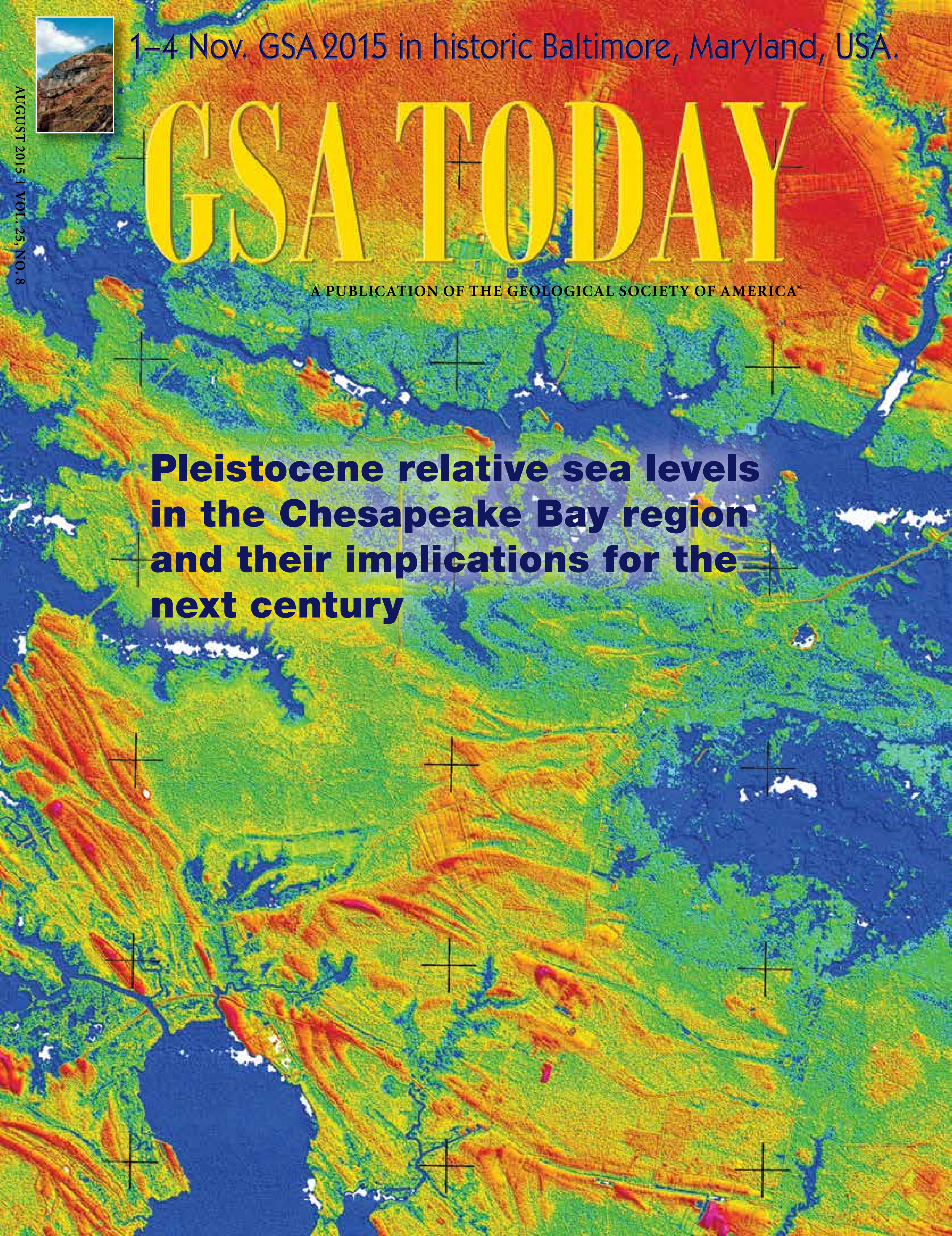
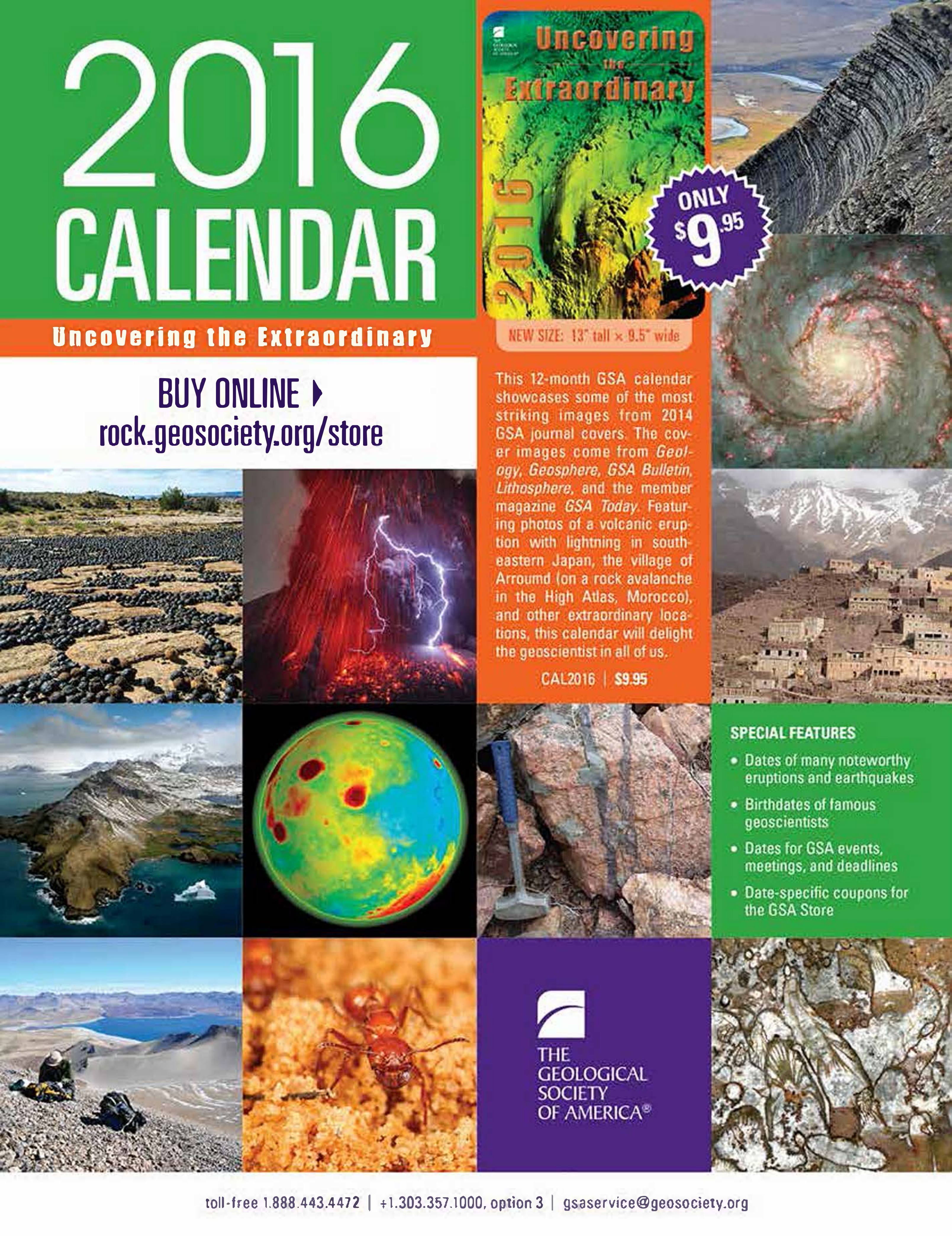
Pleistocene relative sea levels in the Chesapeake Bay region and their implications for the next century





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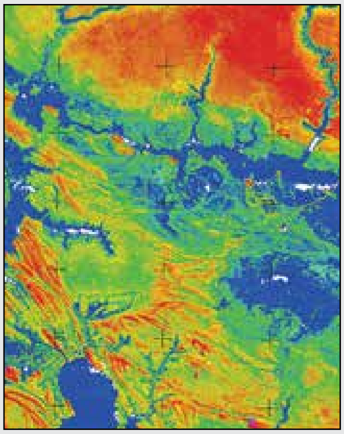
Featured Articles

SCIENCE



Cover: LiDAR-based mapping shows emergent estuarine sand bars along the shore of Chesapeake Bay. DeJong et al. show this landscape formed when sea level was >40 m lower than today. Its present elevation suggests that high rates of relative sea-level rise will continue in the mid-Atlantic region for the foreseeable future. See related article, p. 4–10.

GROUNDWORK

2015 GSA Annual Meeting & Exposition

GSA News

Erratum

On page 28 of the June 2015 issue of *GSA Today*, the logo for the Society of Exploration Geophysicists was mistakenly used instead of the correct logo, seen here, for the Society of Economic Geologists. *GSA Today* regrets this error.

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Cover inset photo. Sideling Hill roadcut. Location: West of Hancock; Washington County, Maryland, USA. Physiographic Province: Ridge and Valley.

Pleistocene relative sea levels in the Chesapeake Bay region and their implications for the next century

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ABSTRACT

Today, relative sea-level rise (3.4 mm/yr) is faster in the Chesapeake Bay region than any other location on the Atlantic coast of North America, and twice the global average eustatic rate (1.7 mm/yr). Dated interglacial deposits suggest that relative sea levels in the Chesapeake Bay region deviate from global trends over a range of timescales. Glacio-isostatic adjustment of the land surface from loading and unloading of continental ice is likely responsible for these deviations, but our understanding of the scale and timeframe over which isostatic response operates in this region remains incomplete because dated sea-level proxies are mostly limited to the Holocene and to deposits 80 ka or older.

To better understand glacio-isostatic control over past and present relative sea level, we applied a suite of dating methods to the stratigraphy of the Blackwater National Wildlife Refuge, one of the most rapidly subsiding and lowest-elevation surfaces bordering Chesapeake Bay. Data indicate that the region was submerged at least for portions of marine isotope stage (MIS) 3 (ca. 60–30 ka), although multiple proxies suggest that global sea level was 40–80 m lower than present. Today MIS 3 deposits are above sea level because they were raised by the Last Glacial Maximum forebulge, but decay of that same forebulge is causing ongoing subsidence. These results suggest that glacio-isostasy controlled relative sea level in the mid-Atlantic region for tens of thousands of years following retreat of the Laurentide Ice Sheet and continues to influence relative sea level in the region. Thus, isostatically driven subsidence of the Chesapeake Bay region will continue for millennia, exacerbating the effects of global sea-level rise and impacting the region's large population centers and valuable coastal natural resources.

INTRODUCTION

The sea level for any location at a given point in time represents a sum of factors, including the volume of ocean water, steric (thermal) effects, tectonic activity, and crustal deformation in response to glacio-hydro-isostatic adjustment (GIA) from loading and unloading of continental ice and water masses (Church et al., 2010). GIA can be a dominant driver of relative sea level (RSL) near ice margins, where the weight of ice displaces the mantle beneath glaciated regions, uplifting a "forebulge" in the peripheral, non-glaciated region (Peltier, 1986). With ice retreat, the forebulge progressively subsides at rates dependent on mantle rheology and lithosphere thickness (Peltier, 1996).

GIA played a role in RSL near the Chesapeake Bay region of the United States (Fig. 1) for many millennia after the ice melted away (Peltier, 2009). GIA effects were first recognized in the region when shoreline deposits ~3–5 m above present sea level, long assumed to be ca. 125 ka (marine isotope stage [MIS] 5e; MIS designations from Lisiecki and Raymo, 2005), were found to have ca. 80 ka ages (MIS 5a; Cronin, 1981). During this time, global average sea level was as much as 20 m below its present level (Fig. 2). While flexural isostatic uplift and subsidence have been documented in the Chesapeake Bay region (i.e., Pazzaglia and Gardner, 1993), the rates (~0.006 mm/yr) associated with these processes are insufficient to account for the age-elevation relationships of MIS 5a shorelines.

The presence of MIS 5a shorelines 3–5 m above present sea level indicates that the land surface within the Chesapeake Bay region was significantly lower during the formation of these shorelines due to regional land subsidence from the collapse of the MIS 6 forebulge, and that the Chesapeake Bay region experienced renewed forebulge uplift during the MIS 2 to raise these shorelines above present sea level (Potter and Lambeck, 2003; Wehmiller et al., 2004). The Holocene stratigraphic record in the Chesapeake Bay region helps illuminate forebulge dynamics; differential subsidence from the collapse of the MIS 2 forebulge caused variable timing and rates of inundation along the eastern seaboard during the Holocene transgression (Peltier, 1996). These differential rates have been exploited to reconstruct the form of the forebulge (Engelhart et al., 2009) and to constrain GIA models (Fig. 1) (Davis and Mitrovica, 1996; Peltier, 1996).

Recent studies employing optically stimulated luminescence (OSL) dating suggest that the lowest-elevation, emerged estuarine deposits within the mid-Atlantic were deposited during MIS 3, significantly extending the inferred duration and magnitude of land subsidence due to collapse of the MIS 6 forebulge. Shoreline

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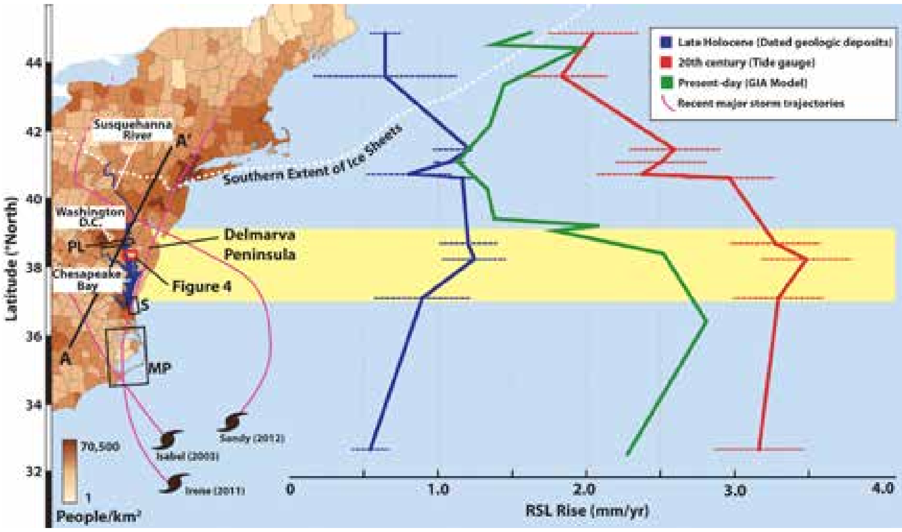

Figure 1. Map showing Atlantic coast of the United States with population density by county (U.S. Census Bureau, 2010) placed alongside Late Holocene and twentieth-century relative sea-level rise (RSL) rise curves (2 σ errors; Engelhart et al., 2009). RSL rise predicted from glacio-hydro-isostatic adjustment (GIA) modeling is from the M2 viscosity model (Peltier, 1996). Yellow shaded region brackets area of highest RSL rise on the Atlantic coast; dotted white line indicates maximum extent of the Laurentide ice sheet (LIS) (Dyke et al., 2002); magenta lines indicate tracks of major recent storms. PL, S, MP—Locations of coastal deposits dating to MIS 3 near central Chesapeake Bay (67–37 ka, $n = 8$; Pavich et al., 2006; Litwin et al., 2013), in southern Virginia (50–33 ka, $n = 2$; Scott et al., 2010), and North Carolina (59–28 ka, $n = 15$; Mallinson et al., 2008, Parham et al., 2013), respectively. A–A′ shows location of Figure 2A.

landforms above sea level (<8 m above mean sea level [asl]) near central Chesapeake Bay (PL, Fig. 1), at the mouth of Chesapeake Bay (S, Fig. 1), and on the North Carolina coast (MP, Fig. 1) indicate estuarine deposition throughout MIS 3 (67–32 ka). Eustatic sea level during this time was highly variable but always ~40–80 m lower than present (Fig. 2) (Siddall et al., 2008). These new data challenge the long-held implication that locations within the Chesapeake Bay region, and specifically the Delmarva Peninsula, did not experience high-stand deposition after MIS 5 (e.g., Ramsey, 2010). The presence of near-shore MIS 3 deposits near present sea level suggests an alternative sea-level history for the region, one that implies forebulge uplift of at least 40 m since the time of deposition. This uplift has been attributed to growth of the last glacial maximum (LGM; MIS 2) forebulge (Pavich et al., 2006; Mallinson et al., 2008; Scott et al., 2010; Parham et al., 2013) that remains uplifted out of isostatic equilibrium (Potter and Lambeck, 2003).

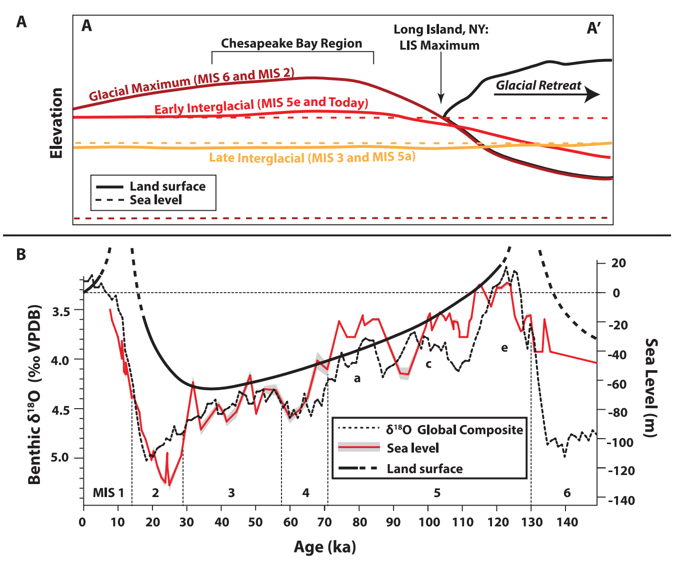

Figure 2. (A) Schematic cross section showing relationship of land surface to relative sea level at specific times in glacial cycles as a function of distance from the Laurentide ice sheet (LIS). Adapted by permission from D. Krantz and C. Hobbs (2014, pers. comm.). Location of A–A′ cross section is indicated in Figure 1. (B) Oxygen isotope and sea-level curves for the past 150 k.y. from Lisiecki and Raymo (2005) and Thompson and Goldstein (2006), respectively. The glacioisostatic (land surface) curve (after Scott et al., 2010) is based on ages produced for shoreline deposits in the mid-Atlantic region and illustrates how land-surface elevation change induced by glacio-hydro-isostatic adjustment can account for submergence of the Chesapeake Bay region when eustatic sea level was much lower than present. VPDB—Vienna Pee Dee Belemnite.

This paper uses multiple methods to date deposits within the zone of greatest subsidence in the Chesapeake Bay region (Fig. 1) and place today's rapid relative sea-level rise into the context of a several-million-year geologic framework. We used a light detection and ranging (LiDAR) digital elevation model (DEM) to analyze low-relief landforms and conducted extensive drilling to constrain the Pleistocene stratigraphic framework. Our data show that regional subsidence related to collapse of the MIS 6 glacio-isostatic forebulge impacted the mid-Atlantic region well into MIS 3, tens of thousands of years after MIS 5 deglaciation. Long-lasting subsidence associated with collapse of the MIS 6 forebulge suggests that present-day subsidence related to the collapse of the MIS 2 forebulge will continue for the foreseeable future. We conclude that ongoing subsidence adds to the impacts of sea-level rise driven by warming climate and melting ice sheets and should be considered in coastal sea-level risk assessments.

STUDY SITE AND METHODS

To reconstruct the sea-level history in Chesapeake Bay, we focused on the Blackwater National Wildlife Refuge (~110 km^2; red-bordered rectangle on Fig. 1), which experienced major inundation and transformation of wetlands to open water in the twentieth century (Fig. 3). Sediment from 70 boreholes was described, analyzed, and sampled. The DEM (Fig. 4) was used to characterize the geomorphology. We constrained the oldest erosional event preserved directly above the underlying Miocene strata using cosmogenic nuclide isochron burial dating (Balco and Rovey, 2008). We dated 28 samples using optically stimulated luminescence (OSL) dating. The OSL ages allow us to develop a

Figure 3. Time series of the Blackwater River valley. Top: Intact marsh surveyed from AD 1902 to AD 1904 and presented in a 7.5″ USGS topographic map from AD 1905 (USGS, 1905); dark blue hatching around the Blackwater valley is tidal marsh; light blue pattern is freshwater swamp. Middle: Initiation of major ponding seen in an aerial photograph from 1938 (http://www.esrgc.org/). Bottom: Coalesced ponds forming the informal "Lake Blackwater" in satellite imagery from AD 2007 (http://www.bing.com/maps/). Wetlands are converting to open water at a rate of 50–150 ha/yr in the field area (Cahoon et al., 2010). Image locations are identified in Figure 4B. Red outline shows location of unnamed island for reference.

geochronological framework for the Blackwater National Wildlife Refuge landforms and estuarine sediments to a depth of ~9 m (Fig. 5). Eight radiocarbon dates constrain the timing of Holocene inundation and the beginning of marsh accretion. Detailed methods are provided in the online GSA Supplemental Data Repository[1].

RESULTS AND INTERPRETATIONS

The Blackwater National Wildlife Refuge is underlain by Pleistocene deposits that vary in thickness from ~3–55 m (Fig. 5). Glacial-interglacial climate fluctuations induced major cycles of localized river incision and aggradation in the Chesapeake Bay region (Colman et al., 1990), and the subsurface Blackwater National Wildlife Refuge stratigraphy includes cut-fill deposits associated with at least three paleochannel systems (Fig. 5). Isochron ages at the base of the Pleistocene section are 1.72 ± 0.08 Ma for a Susquehanna River paleochannel and 2.06 ± 0.14 Ma for a local paleochannel system (2σ; Fig. 5 and GSA Supplemental Data Table S1 [see footnote 1]). The older age indicates that major cutting and filling commenced in the study area shortly after the onset of major Northern Hemisphere continental glaciation (2.4 Ma; Balco and Rovey, 2010). These ages are significantly older than previous age estimates for paleochannels of the Chesapeake Bay (ca. 18–450 ka; Colman et al., 1990). The complex Pleistocene stratigraphic record and age range of material overlying these dated deposits suggest that fluvio-estuarine processes dominated landscape evolution over glacial-interglacial timescales in the field area (Fig. 5).

LiDAR allows us to identify a variety of landforms on the Blackwater National Wildlife Refuge surface that form a continuum with the shallow stratigraphy (<12 m depth; Figs. 4 and 5). A regressive, wave-cut scarp with multiple bifurcations (beach ridges, Fig. 4B) separates upland areas to the north and east from the lower terrain in the south and west that is occupied by an expansive tidal marsh. These shoreline features consist of an ~3 m fining upward sequence of burrowed, silty fine sand to massive, medium sand (GSA Supplemental Data Fig. S5 [see footnote 1]) with an age range of 53–40 ka ($n = 6$; see Fig. 5 and GSA Supplemental Data Table S2). Below the scarp, large subaqueous bars (Fig. 4B) that roughly parallel the paleoshoreline dominate the geomorphology. The bars consist of facies ranging from horizontally bedded, alternating sand and silt to moderately sorted, fine-to-medium sand interpreted as wave-sorted tidal channel deposits and wave-built bars within tidal tributaries or bays. OSL ages for surficial landforms below the scarp range from 69 to 35 ka ($n = 15$). The morphology, lithology, and ages of these features indicate that estuarine conditions prevailed, at least intermittently, during most of MIS 3, with active bar migration continuing during regression. Locally, unconformities separate multiple, stacked MIS 3 deposits, and in some locations MIS 3 deposits cut older estuarine units that were dated to both MIS 5a and MIS 5e (Fig. 5; GSA Supplemental Data Figs. S4 and S5 [see footnote 1]).

The MIS 3 estuarine surface is truncated by a north-south–trending, meandering channel with scroll bars as well as elliptical depressions interpreted as ephemeral basins (Fig. 4B). The rims of basins are composed of laminated, silty, fine-to-medium sand with ages 30–26 ka ($n = 3$); the meandering channel must be younger than the ca. 35 ka sand bars it cuts. The basins and channel are likely relict from periglacial processes that dominated this landscape beginning ca. 30 ka and continued through the LGM (Denny et al., 1979; Newell and Clark, 2008; French et al., 2009; Markewich et al., 2009; Newell and DeJong, 2011; Gao, 2014).

Sediments from the Holocene transgression (yellow, Fig. 5) overlap MIS 3 estuarine deposits within incised valleys of the Blackwater River and its tributaries. They consist of a lower silt (~3–4 m) with locally abundant organic material that transitions to an upper, dense, organic peat (~3–4 m). A radiocarbon (^{14}C) age from woody material near the base of the silt (−8.5 m) suggests

[1] GSA supplemental data item 2015211, data tables and methodology, is online at www.geosociety.org/pubs/ft2015.htm. You can also request a copy from *GSA Today*, P.O. Box 9140, Boulder, CO 80301-9140, USA; gsatoday@geosociety.org.

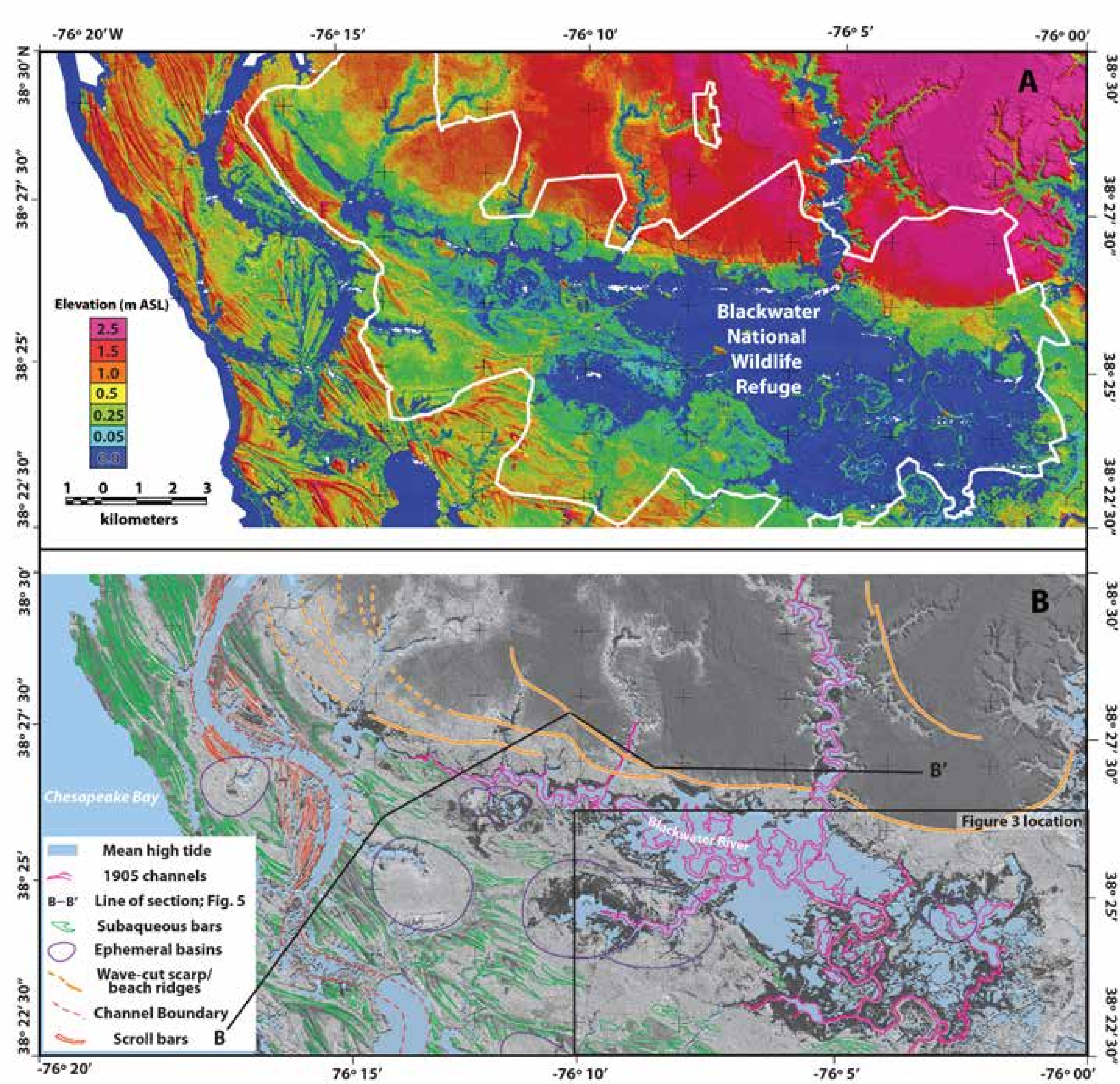

Figure 4. (A) LiDAR-derived digital elevation model (DEM) of the Blackwater National Wildlife Refuge projected with the NAD83 datum; produced by H. Pierce (2012, pers. comm.); m ASL—meters above sea level. Cell size is 2.5 m by 2.5 m; graduated elevation scale indicated to the left of the image exaggerates subtle features in the lowest elevation ranges. White outline indicates boundary of the Blackwater National Wildlife Refuge. (B) Same LiDAR DEM as (A) in gray-scale with geomorphic features referenced in the text superimposed. AD 1905 channel margins were digitized from the topographic map in Figure 3A.

initial Holocene transgression into the Blackwater River valley by 5310–5570 cal yr B.P. Woody material within the silt, just below the peat boundary, is 690–910 cal yr B.P., setting a maximum age for marsh accretion. Radiocarbon samples collected above this boundary and within the peat have modern ages (GSA Supplemental Data Table S3 [see footnote 1]).

DISCUSSION

Fluctuating sea levels, resulting from changes in eustatic sea level, and crustal deformation (uplift and subsidence) related to GIA, define the Pleistocene history of the Blackwater National Wildlife Refuge and the greater Chesapeake Bay region. The Pleistocene record and cosmogenic ages suggest that the onset of Northern Hemisphere glaciation at the Plio-Pleistocene boundary initiated cycles of incision and deposition. The paleo–Susquehanna River and its tributaries responded to repeated ~50–100-m sea-level fluctuations (Lisiecki and Raymo, 2005) with deep incision of river valleys during glacial lowstands and fluvio-estuarine deposition during transgressions. Estuarine conditions prevailed during portions of MIS 3, when global proxies indicate that eustatic sea level was ~40–80 m below present, suggesting prolonged relaxation of a MIS 6 forebulge during MIS 3.

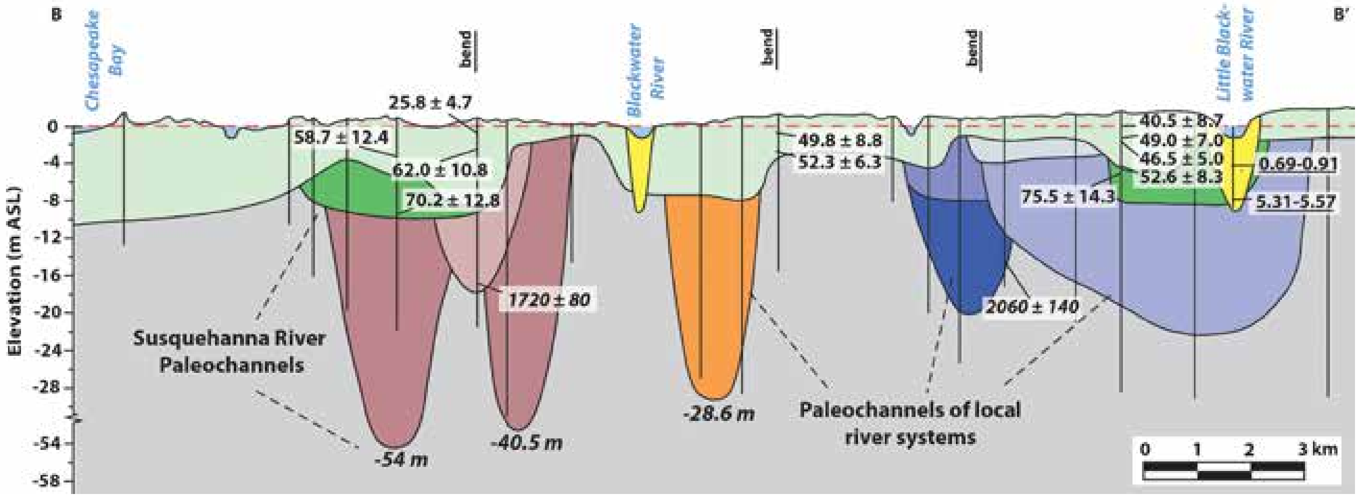

Figure 5. (A) Cross section showing the Pleistocene deposits that underlie the Blackwater National Wildlife Refuge. All ages are in thousands of years (ka). Italicized ages are cosmogenic burial isochrons; underlined ages are radiocarbon ages; all others are optically stimulated luminescence ages. Yellow shading represents Holocene deposits; green shading represents MIS 5 and MIS 3 deposits; shades of red, orange, and blue indicate three distinct paleochannel systems, with depths of western channels inferred from boreholes drilled off the line of section; gray substrate is the Miocene Chesapeake Group. Note break in vertical scale. See Fig. 4B for B–B′ line of section. See GSA Supplemental Data Figures S4 and S5 (see footnote 1) for more detail on sedimentology.

Temperatures and sea levels plunged prior to ca. 30 ka, from their already low MIS 3 levels (Lambeck et al., 2014) (Fig. 2). As the LIS grew, so did the forebulge that uplifted the Chesapeake Bay region through the LGM, likely contributing to rapid incision documented along the Susquehanna and Potomac Rivers (Reusser et al., 2004) as the Chesapeake Bay region was transformed into a periglacial landscape. During the Holocene, the forebulge progressively subsided, as indicated by differential timing of Holocene inundation and variable rates of sea-level rise along the U.S. Atlantic Coast (Engelhart et al., 2009). The Blackwater River valley was inundated by ca. 5 ka, initiating deposition of bay bottom silt. Widespread marshes were established sometime within the last millennium and accreted, keeping pace with sea-level rise. RSL rise accelerated along the U.S. Atlantic coast during the twentieth century (Engelhart et al., 2009), resulting in inundation, erosion, and ponding in the Blackwater National Wildlife Refuge as sea-level rise outpaced marsh accretionary processes (Fig. 3) (Stevenson et al., 2002).

The presence of MIS 3 estuarine deposits near today's sea level confirms the effects of GIA over long timescales for the Blackwater National Wildlife Refuge and supports similar interpretations within the greater Chesapeake Bay region. The elevations of MIS 3 estuarine deposits generally decrease from the Central Delmarva Peninsula southward to North Carolina (Scott et al., 2010); dated, emerged MIS 3 estuarine deposits are not found south of North Carolina. While the maximum elevations of MIS 3 deposits vary (GSA Supplemental Data Fig. S8 [see footnote 1]), decreasing elevations to the south are consistent with the shape of the forebulge based on subsidence rates (Engelhart et al., 2009). High-precision GPS data, though limited to a short time series, also indicate the highest rates of subsidence on the Atlantic coast are centered on the Chesapeake Bay region (Sella et al., 2007; Snay et al., 2007).

Our data support the hypothesis that subsidence in the Chesapeake Bay region is caused by the continued collapse of the MIS 2 forebulge (Potter and Lambeck, 2003). While subsidence rates vary within the Chesapeake Bay region (Fig. 1) (Engelhart et al., 2009), potentially due to local groundwater withdrawal for commercial use (Eggleston and Pope, 2013), the central Delmarva Peninsula has the highest rates of subsidence in the mid-Atlantic region (~1.3–1.7 mm/yr; Engelhart et al., 2009). Parsing GIA-driven subsidence from other RSL drivers is uncertain (e.g., Cronin, 2012), but the agreement of twentieth-century subsidence values calculated from tide gauge records where effects of seasonal and decadal variability are removed (~1.6 mm/yr, Boon et al., 2010) and from dated Holocene deposits (~1.3 mm/yr; Engelhart et al., 2009) from the same location near our study area implies consistency of rates over millennial timescales. Subsidence is thus primarily driven by GIA in the Chesapeake Bay region, which makes RSL rise in the Chesapeake Bay–Washington D.C. area twice the twentieth-century global average rate of sea-level rise (1.7 mm/yr; IPCC, 2013). If timescales of MIS 6 forebulge subsidence are used for comparison, subsidence from the LGM forebulge collapse will continue for many more millennia.

Ongoing GIA-driven subsidence in the Chesapeake Bay region challenges a region already threatened by sea-level rise. At the Blackwater National Wildlife Refuge, we use rate consistency to predict ~0.16 m of subsidence for the region in the twenty-first century (using twentieth-century values from Boon and others [2010] that presumably include the effects of groundwater withdrawal). The likely range of average global sea-level rise for the twenty-first century is 0.33–0.82 m, based on a non-aggressive climate mitigation policy (IPCC, 2013). Superimposing this sea-level rise estimate over 0.16 m of subsidence yields a total predicted RSL rise of 0.49–0.98 m for the Blackwater National Wildlife Refuge by AD 2100.

These are minimum estimates; several lines of evidence suggest that sea levels will rise more quickly in the Chesapeake Bay region. Recent tide gauge analyses indicate the acceleration of sea-level rise in the North Atlantic in recent decades, possibly due to dynamic ocean circulation processes (Yin et al., 2010; Boon, 2012; Ezer and Corlett, 2012; Sallenger et al., 2012). If this acceleration continues, it could induce an additional rise of 15 cm for the Chesapeake Bay and Washington D.C. areas by AD 2100 (Yin et al., 2010). Recent evidence also confirms the instability of glaciers in West Antarctica, which has the potential to raise global sea levels significantly, particularly beyond AD 2100 (Joughin et al., 2014; Rignot et al., 2014). As global sea levels rise and the Chesapeake Bay region subsides, storm surges are projected to increase both in frequency (IPCC, 2013) and magnitude (Tebaldi et al., 2012). Superimposing Hurricane Isabel water levels on the range of RSLs we predict for the Cheapeake Bay region would cause a storm tide of ~3.8–4.6 m in Washington D.C. and ~2.8–3.5 m for Chesapeake Bay (NOAA, 2003). Given the location of the Chesapeake Bay region along the path of storms tracking up the Atlantic coast (Fig. 1), increasing RSL rise will further exacerbate already high costs of storm damage, such as the US$65 billion price-tag associated with Hurricane Sandy (NOAA, 2013).

Even the most conservative estimate of projected RSL rise poses significant threats to the Chesapeake Bay region. Bridges, military facilities, national monuments, and portions of the rapid transit system would be flooded in Washington D.C., and ~70,000 residents would be impacted by a 0.4 m rise in sea level (Ayyub et al., 2012). Island communities in Chesapeake Bay are particularly vulnerable to RSL rise. The last two inhabited islands in Chesapeake Bay are ~1 m above sea level; they occupy the same geomorphic surface as the western portion of our field area and will experience similar rates of subsidence. In the Blackwater National Wildlife Refuge, a LiDAR-based inundation study using a conservative model for sea-level rise shows that the majority of tidal marsh will be inundated by AD 2050 (Larsen et al., 2004).

The elevated risk of flooding in the Chesapeake Bay region is already triggering a societal response. At the Blackwater National Wildlife Refuge, managers are designing corridors for the landward migration of habitat through easements and land acquisition to ensure the persistence of tidal marsh beyond AD 2100. Similar options are increasingly limited on other coastlines, where continued development and site modification for housing severely limit the potential for inland migration of habitat, and wetland loss significantly reduces natural buffers to storms in these regions (Titus et al., 2009). Island communities have limited options; some Chesapeake Bay islands have been abandoned due to sea-level rise in the past century (e.g., Gibbons and Nicholls, 2006).

For Washington D.C. and other coastal cities, risk assessment and adaptation planning based on the full range of possible RSL rise scenarios is critical. The analysis by Ayyub et al. (2012) indicates significant losses for Washington D.C. with a rise of 0.4 m, well below the minimum predicted rise of sea level for AD 2100 of 0.49–0.98 m. This analysis under-predicts the most likely RSL rise over the next century, in part because it does not explicitly consider that GIA will drive increased RSL independent of climate change. We conclude that risk assessments and adaptation planning for sea-level rise should consider the full range of sea-level estimates (e.g., Miller et al., 2013) and take local subsidence values into consideration, particularly for high-density population centers like Washington D.C.

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Baltimore Sites **Highlights**

FELL'S POINT

In 1726, English Quaker William Fell bought the land here and named it "Fell's Prospect." The town, "Fell's Point," was founded in 1763, and in 1775, Fell's Point Ship Yard produced the first frigate of the Continental Navy, the *Virginia*. Fell's Point is now known as a spirited waterfront community that is in perpetual celebration of Baltimore's nautical roots. Chesapeake Bay cuisine is at its best here, whether you crave oysters on the half shell at a local pub or fresh seafood at an upscale restaurant. Learn more at **http://bit.ly/1QFHNiA.**

LITTLE ITALY

Benvenuto a Little Italy! By far, the biggest draw of this neighborhood is the food. The aroma of home-style dishes wafts from numerous restaurants, bakeries, and delis. Ask around for the best Italian restaurant in Little Italy and you'll get a different answer every time—It's hard to choose when everything is delicious. Little Italy, which was founded in 1849, also features the Star-Spangled Banner Flag House, the Reginald F. Lewis Museum of Maryland African American History & Culture, and the Baltimore Civil War Museum at President Street Station. Learn more at **http://bit.ly/1HjdRbz.**

ARTS DISTRICTS

Baltimore features three state-designated art districts. Located just steps from Penn Station, the Station North A & E District is home to art in many forms, from street art to curated exhibits. The Highlandtown A & E District is culturally diverse, with art galleries and retail shops. Built in 1911, the 15-story Bromo Seltzer Arts Tower has been transformed into studio spaces for visual and literary artists. Every week, the artists open their studios to visitors and host events throughout the year. Learn more at **http://baltimore.org/see-do/arts-districts.**

Photos courtesy of Visit Baltimore.

http://baltimore.org/article/baltimore-inner-harbor

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AT THE MEETING

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The Pathways to a Successful Career: Building Value Workshop
Saturday, 31 Oct., 1–4 p.m.

Career Panels

Geology in Industry Career Pathways Luncheon
Sun., 1 Nov., 11:30 a.m.–1 p.m.

Geology in Government Career Pathways Luncheon
Mon., 2 Nov., 11:30 a.m.–1 p.m.

The Paleontological Society Mentors in Paleontology Careers Luncheon
Mon., 2 Nov., noon–1 p.m.

Networking

Women in Geology Career Pathways Reception
Sun., 1 Nov., 5–6:30 p.m.

Student Networking Luncheon
Tues., 3 Nov., 11:30 a.m.–1 p.m.

Employment

Résumé Clinic
Sun., 1 Nov., 9 a.m.–5 p.m.

GeoCareers in Industry—Connecting Students and Industry
Full day events to interact with company representatives
Sun., 1 Nov., 9 a.m.–5:30 p.m.

GeoCareers Interview Service
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community.geosociety.org/gsa2015/science-careers/careers

Workshops

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Science communication strategies for interacting with the public, policymakers, and social media
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Preparing & Publishing Papers: A workshop for early-career geoscientists
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Mentoring is a powerful way to guide a student toward future success.
Please consider mentoring an On To the Future (OTF) student at this year's meeting.
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The Art & Science of Chasing Ice

James Balog, *Founder & President, Earth Vision Institute & Extreme Ice Survey*

Monday, 2 Nov., 12:15–1:15 p.m.

For more than 30 years, photographer James Balog ("BAY-log") has broken new conceptual and artistic ground on one of the most important issues of our era: human modification of our planet's natural systems. To reveal the impact of climate change, Balog founded the Extreme Ice Survey (EIS), the most wide-ranging, ground-based photographic study of glaciers ever conducted. He and his EIS team were featured in the 2012 internationally acclaimed, Emmy® award-winning documentary, *Chasing Ice*, and in the 2009 NOVA special, *Extreme Ice*. Balog is the author of *ICE: Portraits of Vanishing Glaciers* and seven other books. His photos have been extensively published in major magazines, including *National Geographic*, and exhibited at more than 100 museums and galleries worldwide.

In this visually stunning presentation, Balog shares the latest photography and image sequences from the EIS. Balog and his team braved treacherous conditions—crevasses, rockslides, avalanches, temperatures down to –40 °F, and frigid river crossings—and the images they captured provide the "smoking gun" of climate change—evidence that every audience can understand. His lecture will provide a fascinating exploration of humanity's relationship with nature and a profound understanding of how climate change is affecting our planet. It is nothing short of a call to arms to one of the greatest challenges of our generation.

The Geological Society of America®

GEOCAREERS Mentoring Tomorrow's Geoscience Leaders at the 2015 Section Meetings

GSA is proud to provide mentoring and career pathway events at all meetings. At Section Meetings, students are invited to participate in 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. With additional financial assistance from GSA's Northeastern and Southeastern Sections, mentor volunteers and students met in a relaxing, informal setting, to discuss careers in geology over lunch.

This past spring, 572 students and 60 mentors participated in the Shlemon Program, and 244 students and 29 mentors attended the Mann Program. Both mentors and students left the events expressing feelings of personal and professional growth. As a result, new friendships were made and professional contacts were established that will last well into the future.

In addition to mentoring, GSA provided three career workshops for students, designed to help them plan and prepare for their job search. The workshops covered career planning and informational interviewing, career exploration, and cover letters, résumés, and CVs. Working professionals from academia, government, and industry were invited to answer questions and help them maneuver the career exploration process.

GSA gratefully acknowledges the following mentors for their individual gifts of time and for sharing their insight with students. To learn more about these programs, or to be a mentor at a future Section Meeting, please contact Jennifer Nocerino, jnocerino@geosociety.org.

The John Mann Mentors in Applied Hydrogeology Program

Helping Mentor Students Since 2004

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Richard Gray, DiGioia, Gray & Associates LLC
Gretchen Hurley, Bureau of Land Management
Ranie Lynds, Wyoming State Geological Survey

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Geoscience Career Exploration Workshops

Helping Mentor Students Since 2015

SOUTH-CENTRAL SECTION
Douglas Gouzie, Missouri State University
Cindy Smith, ConocoPhillips
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ROCKY MOUNTAIN SECTION
Lawrence Braile, Purdue University
Randall Childers, Unimin Corp.
Gretchen Hurley, Bureau of Land Management

The Importance of Networking

It is likely you've heard that most people find their jobs through networking, not researching on Internet job boards. In fact, the U.S. Bureau of Labor Statistics suggests that 70% of all jobs are gained through networking. But what is networking really, and more importantly, how do you get started?

GSA's career manager recently spoke with Patrick McAndless, P.Geo, FGC, career coach and founder of the online career resource Geodude Corner (http://geodudecorner.com) to ask some questions about networking. What follows are some of his responses.

Is networking really as important as others suggest?

Employers are looking to hire people with passion, a strong work ethic, persistence, and the ability to always improve themselves. These attributes are important because they are the indicators that show that an individual has the potential to add value and make a difference to an organization or company. The only way an employer can see whether a candidate has these attributes is through networking.

Networking allows you to connect with others, no matter what their background, and to gain insights into employment opportunities while getting your own interests, experiences, skills, and abilities communicated to the right companies. Networking can provide powerful insight into how a potential employee can add value to a company.

Where can a student begin networking?

There are many ways and places to practice networking and communicating your interests, experiences, skills, and abilities to potential employers. Conferences, like GSA's Annual and Section Meetings, are arguably the best networking opportunities simply because you can expand your network considerably in one place. Conferences provide opportunities to learn not only about different aspects of geoscience, they also offer specific networking events. Your university can also be a great place to expand your network through organized career fairs and student-industry nights where students can meet potential employers and gain an appreciation of how a company operates.

Other networking opportunities can be created by volunteering in the geoscience department of a university or in the community with non-profit organizations. Volunteering shows your commitment to an organization and can provide valuable insight into how you will perform on the job. Through volunteering you may also meet new people that you can add to your existing network. LinkedIn is also a great resource, where you can showcase your education, interests, and career direction while connecting with networks and associations in your area of geoscience interest.

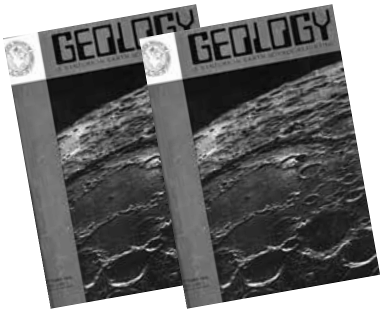
How should a student prepare to network?

Every student, whether close to graduating or not, should start to build a marketing plan that will lead to a successful career in the geosciences. It is a fact that employment opportunities are acquired through a well-thought-out and organized networking strategy. Effective networking is the best way to draw attention to those attributes employers are looking for: passion, a strong work ethic, persistence, and always improving. Plan to communicate your interests, experiences, skills, and abilities through connecting with others in a face-to-face setting at networking events, conferences, and industry nights. Prepare a student business card with a geoscience picture, your contact information, and your areas of interests or geoscience experience to hand out at events. Remember to always be prepared by conducting research on the companies you are interested in beforehand and prepare a set of engaging questions to ask.

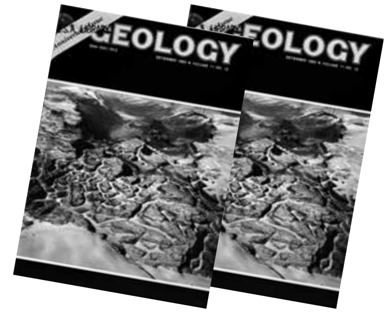
To learn more about networking, and to see examples of student business cards and other marketing tools, go to http://geodudecorner.com. McAndless will also be facilitating the GeoCareers in Industry: The Pathway to a Successful Career: Building Value Workshop to be held at the GSA 2015 Annual Meeting & Exposition on Sat., 31 Oct., and hosting a Résumé Clinic on Sun., 1 Nov.; see **community.geosociety.org/gsa2015/science-careers/careers.**

GEOCAREERS Corner

with Tahlia Bear,
GSA Careers & Diversity Program Manager



Geology—Past & Future REVISITED



Editor's note: The following is the eleventh and final installment of our encore presentation of articles that highlighted the 10th anniversary of the first issue of *Geology*, as published in *Geology* in Dec. 1983 [v. 11, no. 12, p. 679–691, doi: 10.1130/0091-7613(1983)11<679:GAF>2.0.CO;2]. Each section was written by a different author (author affiliation notations are as originally published in 1983). See the August 2013 *GSA Today* (v. 23, no. 8, p. 18–19) for the first installment and table of contents. In this issue: article 22: **"Perspectives from Earth,"** by Ivo Lucchitta; and article 23: **"Epilogue,"** by E.M. Moores.

Perspectives from Earth

Ivo Lucchitta, *U.S. Geological Survey, Flagstaff, Arizona 86001*

Ten years ago, geology was in the midst of a remarkable change of perspective and temperament. The fusty and dusty image was disappearing, replaced in the eye of public and practitioner alike by a perception of dynamic success, a science on the go. Those were the heady days of space exploration and of geologists on TV news, explaining some awesome spectacle of nature. The energy crisis helped geology's image too—natural resources were becoming scarce or unavailable, and the geologist held the key to finding more. As far as anyone could see, the future was golden for the earth sciences.

The geologist's perspective of the science has been changing apace. Contrary to earlier ideas of stability, it now is clear that nothing is in place, everything moves. Terranes, if not suspect, are at least detached. Even ancient continents, the last bastion of reliable stability, can split apart, the divorced pieces drifting off on separate journeys. Parmenides is out, Heraclitus in, Wegener vindicated. Plate tectonics, once a theory, now a doctrine, with its wonderful ability to explain things that we could only describe before, has seen to that.

The idea that sudden events may shape the world as effectively as the slow grind of evolutionary processes received a great boost from contemplation of the old, scarred surface of the Moon, each scar produced by an awesome catastrophe. Could such events, occurring on Earth, be responsible for the peculiar mass extinctions that punctuate the geologic record? Time—as measured by events and by change—clearly does not flow at a constant rate.

Mobility and catastrophism were joined in the collective consciousness by an expansion of conceptual horizons derived from our increasing familiarity with the solar system. This expansion has been both projective and reflective. It is projective in that we have found that concepts and techniques laboriously developed during the centuries on Earth can be applied with equal success to other planets. It is reflective in that knowledge of the planets helps us understand Earth, especially its obscure history, and in the concept of limits and finiteness. One of the most moving images yet seen is the Apollo picture of Earth, a lonely sphere glowing bluish against the deep velvet of space. Earth may no longer be unique in the eyes of the scientist, but it remains unique to the scientist-as-human-being. There *is* no other Earth.

This perspective from space merely symbolizes, in a particularly elegant way, the view that is still not adequately evident on Earth—of limitation, constraint, and exhaustion of resources. The decade that seemed to usher the (geologists') millennium is ending in rags. Jobs and money are scarce, anti-intellectual rumblings on the rise. Resources are not infinite; demands outstrip availability, and the resulting competition unavoidably entails tradeoffs and painful choices. Geologists hold much knowledge that can lead to wisdom in dealing with resources and environment; this knowledge will be increasingly in demand. In the coming decade, geologists will be asked to do more things of societal import, and they will find themselves entrained ever more by the conflicting currents that agitate society. Geology, and science in general, must reexamine and redefine their relationship to society more closely and carefully.

The issues are many. To what extent, for example, should science have a direct voice in shaping public policy? To what extent should scientists be active in public affairs? How should we reconcile the probabilities and uncertainties of science with the need of society for concrete information on which to act? Formerly, we could indulge our illusion that science is separate and insulated from the rest of the world. In the future this may not be possible and probably would not be wise, given the

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Send brief comments to gsatoday@geosociety.org. Should this article spark a longer comment, please consider writing a *GSA Today* Groundwork or science article; learn more at www.geosociety.org/gsatoday/.

alarming Orwellian undertones of the hyperspecialization of our times, which tends to stunt the human context of science.

It is essential for society to acknowledge and support untrammeled inquisitiveness. Society, however, has a right to expect, in return, knowledge and advice. We can serve both masters—science and society—without compromising our integrity, but our attitudes must change deeply. There must be less separation and ranking of the “pure” and “applied” scientist, who should merge to a considerable degree and to the benefit of all. We must attain greater efficiency in our scientific work by utilizing our intellectual resources more fully. The right side of the brain must be used as well as the left, intuition as well as logic, image as well as language, in order to achieve greater knowledge and to place this knowledge in the human context, where it belongs. Communication must be more lucid and forceful, because thoughts or knowledge unexpressed, or poorly expressed, are of little public value. There must be more interaction with society, and a greater breadth of interests and knowledge to make this interaction possible.

I see a time of change, a time of stress, a time of opportunity, and I look forward with hope to the whole person resurgent, the scientist-philosopher, the citizen-scientist.

Epilogue

E.M. Moores

Some common themes emerge in the foregoing essays: (1) The division between “basic” and “applied” will continue to diminish as the same problems crop up in several fields; for example, the understanding of fluid behavior and transport through fractured media is clearly crucial in such fields as igneous and metamorphic petrology, sedimentology, stratigraphy, mineral resources, tectonics, or hazardous waste isolation, but fluid transport through fractured media is still an unsolved problem in geohydrology. (2) The U.S. needs a more consistent national commitment to resolution of problems involving earth science. (3) Episodic development, possibly though catastrophes, is a more common geologic process than previously thought, and it unifies the formerly separate fields of planetary geology and biostratigraphy. (4) We need more data collected properly—i.e., not randomly, but to answer questions or test hypotheses.

One matter alluded to in a few of the essays is that the most important question regarding the predictions for the next ten years is not whether they will come true but whether we will be around to find out. Must we continue, as Samuel Johnson put it, to “roll helpless down the torrent of our fate”? What, if anything, can earth scientists contribute to prevention of the ultimate catastrophe? Several of the essayists suggest possibilities: (1) we can continue to lend our expertise to efforts to verify any present or future test ban treaties; (2) we can reduce mutual paranoia by encouraging international scientific exchange and resisting efforts to restrict academic freedom or the flow of information; (3) we can provide decision-makers with our perspective based upon our knowledge of geologic time, the rate of geologic processes, the finiteness of Earth’s resources, and Earth’s uniqueness in the solar system. We might point out that *Homo sapiens* probably has only one chance, this one, to succeed. It would be no big deal, geologically speaking, if he/she became just another fossil.

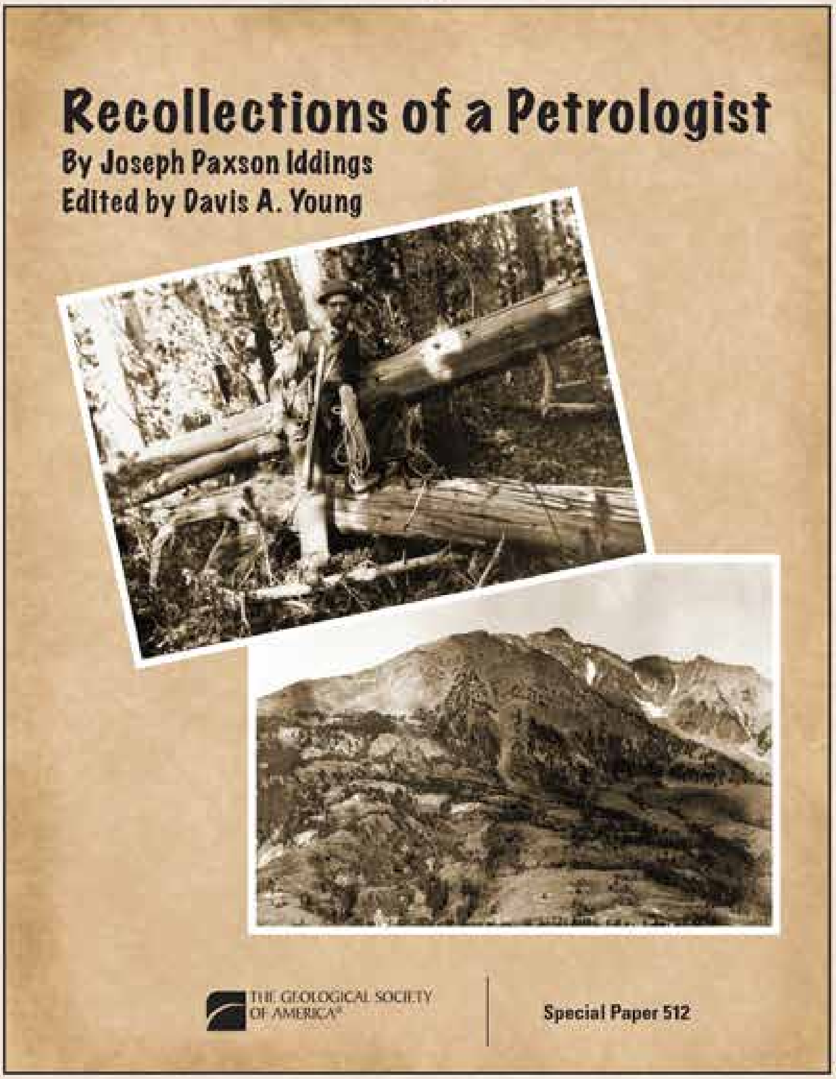
Will these activities suffice? Probably not. What else can we do?

Recollections of a Petrologist

by Joseph Paxson Iddings
edited by Davis A. Young

IN PRESS

In *Recollections of a Petrologist*, Joseph Paxson Iddings (1857–1920), the leading American igneous petrologist of his era, recounts his illustrious career with the U.S. Geological Survey and the University of Chicago. A major participant in the transition from hand-specimen petrography to theoretical igneous petrology based on microscopical petrography and physical chemistry, Iddings deciphered the igneous geology of Yellowstone National Park, spearheaded the CIPW quantitative igneous rock classification project, and wrote several magisterial petrology texts. In *Recollections*, Iddings sheds light on the central petrologic issues of his time in a lucid narrative interspersed with assessments of the personalities and achievements of geological contemporaries, literary allusions, poems, humorous stories, and a wealth of vivid descriptions and impressions of the cultures of Far Eastern countries. No petrologist, mineralogist, or historian of geology should miss the pleasurable reading offered by *Recollections*. Editor Davis A. Young has supported Iddings' lively text with a substantive introduction and hundreds of biographical notes.



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Positions Open

STRUCTURAL GEOLOGIST/NEOTECTONICS GEOLOGY, MISSOURI STATE UNIVERSITY

The Department of Geography, Geology, and Planning invites applications for a tenure-track position in Geology at the rank of Assistant Professor to begin in either January 2016 or August 2016 with an emphasis in **either Structural Geology or Neotectonics.**

A Ph.D. (or ABD) in Geology or a closely related field is required at time of appointment. Requirements include a commitment to undergraduate- and Master's-level teaching as well as research expertise and interest at a level appropriate to supervise Master's-level thesis projects. The successful applicant will teach an undergraduate course in structural geology and one or more upper-level courses in his or her specialty. Additionally, the individual will also teach introductory-level geology courses, and participate in department-level field trips. Post-doctoral research experience and evidence of teaching effectiveness would be advantageous. Applicants must be able to demonstrate knowledge of and the ability to work in an environment that encourages an understanding of, respect for, and development of skills to engage with those of other cultures or diverse backgrounds.

The Department grants undergraduate degrees in Geology, Geography, Planning, Geospatial Science, and Earth Science Education and an M.S. in Geospatial Science in Geography, Geology and Planning. The successful applicant would be expected to teach and advise in the undergraduate program in Geology and in the department's graduate program.

Qualified applicants should apply online at https://jobs.missouristate.edu and upload a single PDF that includes a letter of application, current curriculum vitae, detailed research plan, statement of teaching philosophy, and contact information for 3–5 professional references. The evaluation of applications will begin September 15, 2015, and will continue until a successful candidate is found. Further information can be obtained at +1-417-836-5800 or visit our web site at http://geosciences.missouristate.edu. The University is dedicated to the goal of building a culturally diverse and inclusive faculty and staff committed to teaching and working in a multicultural environment and strongly encourages applications from women, persons from underrepresented ethnic and racial groups, individuals with disabilities and covered veterans. Employment will require a criminal background check at University expense. Missouri State University is an Equal Opportunity/Affirmative Action/Minority/Female/Veterans/Disability employer and institution.

TWO POSITIONS: STRATIGRAPHY/SEDIMENTOLOGY AND GEOMORPHOLOGY/CLIMATOLOGY DENISON UNIVERSITY

Denison University invites applications for two tenure track positions in the Department of Geosciences, to begin in August 2016. We seek broadly trained scientists engaged in the study of (1) Sedimentology and/or Stratigraphy, and (2) Geomorphology and/or Climatology. We welcome candidates that combine these specialties in innovative ways, and are willing to consider joint applications. Successful candidates should demonstrate potential to be outstanding teachers, active scholars, and contributors to the continued growth of the Department and College. Candidates must have a Ph.D. at the time of appointment.

We seek colleagues who are committed to teaching excellence in the liberal arts tradition, are field-based, have broad interests beyond their individual specialties, and will provide a balance of classroom, field, and laboratory experiences for our students. Candidates must have the desire and ability to teach courses at all levels of the curriculum. The typical teaching load is three lab courses per year. In addition, successful candidates are expected to maintain vibrant and productive research programs that actively incorporate undergraduate students.

Denison University is a highly selective, private residential liberal arts college enrolling approximately 2100 undergraduate students from across the country and around the world. The college is located in the village of Granville, Ohio, 25 miles east of Columbus. For more information about Denison, visit our website at www.denison.edu.

All application materials will be handled electronically at https://employment.denison.edu. (Please clearly indicate the desired position.) Applications must include: (1) a letter of application addressing the position requirements listed above; (2) a current curriculum vita; (3) academic transcripts of undergraduate and graduate course work (unofficial acceptable); (4) a statement of teaching philosophy and experience; and (5) a statement of your research program in a liberal arts context. In addition, please include the contact information for three persons who know your teaching and scholarship well, who will then be requested to upload reference letters. Completed application materials submitted by October 15, 2015, will receive full consideration, and evaluation will continue

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until the position is filled. For those attending, we plan to meet with selected candidates at the 2015 GSA Annual Meeting in Baltimore, Maryland.

To achieve our mission as a liberal arts college, we continually strive to foster a diverse campus community, which recognizes the value of all persons regardless of religion, race, ethnicity, gender, sexual orientation, disability, or socioeconomic background. For additional information and resources about diversity at Denison please see our Diversity Guide at http://denison.edu/forms/diversity-guide. Denison University is an Affirmative Action, Equal Opportunity Employer.

FACULTY POSITION
GEOLOGY OR GEOPHYSICS
UNIVERSITY OF MICHIGAN

The Department of Earth and Environmental Sciences at the University of Michigan anticipates an opening for a tenure-track assistant professor in the areas of geology or geophysics for a university-year appointment starting September 1, 2016. The Department intends to pursue additional hires in this direction in future years, and we are particularly interested in candidates whose strengths will complement existing research programs within the Department.

Geology: We encourage applications from candidates whose research interests encompass the origin, evolution, or dynamics of the continents. The successful candidate will develop a strong field-based research program, complemented by expertise in modern analytical techniques or in numerical or analogue modeling. Candidates with an interest in understanding continental evolution in deep geologic time are particularly encouraged to apply.

Geophysics: We encourage applications from candidates who will develop an observationally based research program using geophysical methods (e.g. seismology, geodesy, or potential fields) to study the Earth at the crustal or continental scale. We are particularly interested in those applicants whose work is relevant to societal concerns including natural hazards, such as earthquakes, volcanism, and associated hazards, or environmental change to the hydrosphere or cryosphere.

The successful candidate is expected to establish an independent research program and contribute to both undergraduate and graduate teaching. Applicants must have a Ph.D. at the time of appointment, and should submit a CV, statement of current and future research plans, statement of teaching philosophy and experience, evidence of teaching excellence (if any), and names and contact information of at least four persons who can provide letters of recommendation.

Information about the Department and instructions for submitting an application can be found at www.lsa.umich.edu/earth.

To apply please go to http://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 Michigan-Earth-Search@umich.edu.

The application deadline is September 15, 2015, for full consideration, but applications will continue to be reviewed until the position is filled. Women and minorities are encouraged to apply. The University of Michigan is supportive of the needs of dual career couples and is an equal opportunity/affirmative action employer.

GEOPHYSICS, DEPARTMENT OF EARTH SCIENCE, UC SANTA BARBARA

The Department of Earth Science at the University of California, Santa Barbara, invites applications for a tenure-track Assistant Professor position in Geophysics, starting July 1, 2016. We seek an innovative geophysicist who investigates solid Earth processes with modern geophysical data and/or simulation methods. All areas of technical expertise will be considered, with preference for seismology, geodesy, and/or numerical modeling. We seek candidates who complement our current research program and integrate tectonics and geophysics.

The successful candidate is expected to develop a vigorous, externally funded research program and to advise graduate and undergraduate students. A Ph.D. or an equivalent degree is required at the time of appointment.

Applicants should submit a PDF containing a letter of application, their curriculum vitae, a description of teaching and research objectives and accomplishments, and the contact information of three referees who will provide letters. Applicants should request that the three referees send letters of evaluation by October 1st, 2015. The application file and letters of reference should be submitted to https://recruit.ap.ucsb.edu.

Review of applications will begin October 1st, 2015. The position will remain open until filled, but to ensure full consideration, application materials should be submitted by this date.

The department is especially interested in candidates who contribute to the diversity and excellence of the academic community through research, teaching, and service.

The University of California is an Equal Opportunity/Affirmative Action employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, protected veteran status, or any other characteristic protected by law.

PHYSICAL HYDROGEOLOGIST, GEOLOGY WEST VIRGINIA UNIVERSITY

West Virginia University Department of Geology & Geography invites applications for a tenure-track position in geology at the Assistant Professor level. This position, related to the stewardship of freshwater resources, is one of several university-wide, research-focused initiatives (http://research.wvu.edu/about). Research on freshwater is an area of growth across campus and includes a new interdisciplinary Water Center.

Applicants are expected to hold a Ph.D. or equivalent degree in Geology or related field at the time of appointment. We seek applications from individuals with interests in basic and applied aspects of groundwater flow in the critical zone and/or deeper regimes. The successful applicant will possess demonstrable expertise in study of subsurface water flow and/or transport processes that may be applied to competitively-funded research problems. Specialties may include, but are not limited to, flow modeling in porous media; hyporheic or vadose zone processes; groundwater-surface water interaction; flow in fractured media; hydrogeology of energy-related activities; water supply and sustainability; contaminant and solute transport; and/or karst hydrogeology. The position will begin in January or August 2016.

Candidates will be evaluated on the basis of their potential to establish a vigorous externally-funded research program, publish scholarly work, mentor graduate students, and to teach at the undergraduate and graduate levels. Qualified applicants should submit the following items to hydrogeo@mail.wvu.edu: (1) a single PDF file including a statement of research interests, a statement of teaching philosophy, and curriculum vitae; and (2) pdf files of up to 4 publications. Please also arrange for three letters of reference to be sent to the same email address.

Review of applications will commence on September 15, 2015 and continue until a successful candidate is identified. For additional information, please see http://pages.geo.wvu.edu/hydrogeo or contact the search chair Dorothy J. Vesper at djvesper@mail.wvu.edu. WVU is an EEO/Affirmative Action Employer and welcomes applications from all qualified individuals, including minorities, females, individuals with disabilities, and veterans.

FACULTY POSITION
EARTH AND PLANETARY SCIENCE
DEPARTMENT OF EARTH SCIENCE
RICE UNIVERSITY

We seek creative and promising candidates across the broad spectrum of earth and planetary science who complement the disciplines represented in our department.

Successful candidates are expected to direct an active research program, supervise graduate research, and teach courses for undergraduate and graduate students. Details about the department and its facilities can be found at http://earthscience.rice.edu

Please send a CV, research and teaching statements, and names of four or more references to esci-search@rice.edu.

Equal Opportunity Employer—Females/Minorities/Veterans/Disabled/Sexual Orientation/Gender Identity.

CHAIR, DEPARTMENT OF EARTH AND ENVIRONMENTAL SCIENCES, UNIVERSITY OF WATERLOO

The Department of Earth and Environmental Sciences, in the Faculty of Science at the University of Waterloo invites nominations and applications for the position of Chair of the Department. Candidates must have a Ph.D. and are expected to have a distinguished record of teaching and research as well as demonstrated ability in leadership and administration. They should also be eligible for a faculty position, normally at the level of full professor. The successful candidate will lead the academic and research vision for the Department, be responsible for the relationship between the department and the broader university academic community, and play a leading role in the academic planning and management process within the Faculty of Science.

The salary range for this position is $140,000 to $180,000. Negotiations beyond this salary range will be considered for exceptionally qualified candidates.

The Department has 21 full-time members of faculty, 4 research faculty members, 29 staff, approximately 100 graduate students, 25 post-doctoral fellows and research associates and over 250 Honours undergraduate students in Earth and Environmental Sciences related programs. In addition, the Geological Engineering program, with approximately 100 undergraduate students, is shared with the Department of Civil and Environmental Engineering. Undergraduate studies are available in both a Co-operative Education and Regular format. The Department fosters a dynamic and thriving research environment with over $15 million in annual research, houses a CERC Chair and 2 CRC's (Tier 1) and initiated the Southern Ontario Water Consortium (>$55 million) and the Canadian Water Network. The Department attracts outstanding Canadian and international applicants to its graduate programs. Collaborative research programs that are global in scope are currently active with members of the Faculties of Science, Environment, Mathematics and Engineering and the Water Institute. The Department is interested in strengthening these transdisciplinary initiatives and expanding ties within the national and international academic communities.

The University of Waterloo is located in the attractive and vibrant two-university community of Kitchener-Waterloo (population 500,000) in southwestern Ontario, about 100 km west of Toronto.

Applications and nominations should include a detailed resume, the names and contact information for three individuals willing to provide references, and a statement of capabilities and qualification. The closing date for applications is October 15, 2015. The anticipated start date is September 1, 2016. Send applications or nominations to: Professor Robert Lemieux, Dean, Faculty of Science, University of Waterloo, 200 University Avenue West, Waterloo, Ontario, Canada N2L 3G1, Phone: +1-519-888-4591; Fax: +1-519-746-2543, e-mail: lweber@uwaterloo.ca.

The University of Waterloo respects, appreciates and encourages diversity. We welcome applications from all qualified individuals including women, members of visible minorities, Aboriginal peoples, and persons with disabilities. All qualified candidates are encouraged to apply; however, Canadian citizens and permanent residents will be given priority. Three reasons to apply: https://uwaterloo.ca/watport/why-waterloo.

ASSISTANT PROFESSOR
MINERALOGY-PETROLOGY-EARTH MATERIALS
WEST VIRGINIA UNIVERSITY

The Dept. of Geology and Geography at West Virginia University seeks to hire a tenure track Assistant Professor specializing in Earth Materials. This could include expertise in Igneous, Metamorphic, Sedimentary or Organic Petrology, Mineralogy, Geomicrobiology, or related fields. The successful candidate will be expected to develop a vigorous externally funded research program, to teach core undergraduate classes covering the origins of rocks and minerals as well as graduate courses in the area of his/her expertise, and to mentor graduate students.

Requirements include a Ph.D. or equivalent doctoral degree in Earth Science or a closely related field by the start date, evidence of potential to establish a strong externally-funded research program, to publish in peer-reviewed journals, and to excel in teaching at the undergraduate and graduate levels.

Qualified applicants should: (1) submit a single PDF file including a statement of research interests, a statement of teaching philosophy, and a curriculum vitae; (2) submit PDF files of up to 3 publications; and (3) arrange for three letters of reference to be sent. All documents should go to earthmaterials@mail.wvu.edu.

Review of applications will begin Sept. 30, 2015, and continue until the position is filled. The anticipated start date is August of 2016.

For additional information, please see http://pages.geo.wvu.edu/earthmaterials or contact the search chair: Jaime Toro at earthmaterials@mail.wvu.edu or +1-304-293-9817.

West Virginia University is an EEO/Affirmative Action Employer and welcomes applications from all qualified individuals, including minorities, females, individuals with disabilities, and veterans.

SURFACE GEOLOGIST
NORTH DAKOTA GEOLOGICAL SURVEY

The North Dakota Geological Survey announces a permanent position opening for a geologist. Successful applicant will be responsible for generating maps and reports on the surface geology of North Dakota.

Applicants should have a master's degree in geology. Applicants must have strong written and verbal communication skills. Preference will be given to applicants with experience in the following areas; geologic surface mapping of glacial deposits or Fort Union strata, geologic hazards mapping, and delineation of sand and gravel deposits.

The successful applicant will be hired with a salary dependent upon the level of completed education and applicable experience. The State of North Dakota has very competitive health insurance and retirement plans. Deadline for applications is September 1, 2015.

For more information about the North Dakota Geological Survey and instructions on how to apply for this position, see https://www.dmr.nd.gov/ndgs/. The North Dakota Geological Survey is an Equal Opportunity Employer.

GROUNDWORK

Furthering the Influence of Earth Science

Connecting geology and Native American culture on the reservation of Acoma Pueblo, New Mexico, USA

Darryl Reano *and* ***Kenneth D. Ridgway,*** *Earth, Atmospheric, and Planetary Sciences Department, Purdue University, West Lafayette, Indiana 47907, USA; dreano@purdue.edu, ridge@purdue.edu*

STEM education focused on the perspectives and needs of Native American students is a missing element in the current U.S. educational system (Barnhardt, 1997). Consequently, very few Native American students pursue careers in the STEM disciplines, especially earth science (Beede et al., 2011). Ironically, many Native American students eventually learn that earth science is a tool their ancestors used for thousands of years and that a general mastery of science and engineering skills can benefit and help maintain their communities. Most Native students, however, see no connection between Western science and the goal of preserving their cultural identities. If STEM faculty, teachers, and other scientists can better explain the links between traditional indigenous knowledge, Western science, and community needs, we contend that this approach would attract more Native American and other underrepresented students to earth science.

Earth science is especially relevant for Native communities because it ties directly into the landscape, which often has sacred implications for Native communities, and also to the natural resources that they need in order to function and prosper. An understanding of the geologic framework of tribal lands is vital not only for present-day resource management but also for future long-term decision making that will benefit future generations of Native communities. These important links between Native communities and earth science can be nurtured and strengthened by integrating them into education. Previous research has documented preliminary success in attracting Native students to geoscience courses that incorporate indigenous knowledge, Native worldviews, and culturally appropriate curricula (Semken and Morgan, 1997; Gibson and Puniwai, 2006; Palmer et al., 2009).

The purpose of this article is to present an example to the earth-science community of how a geologic discipline, in this case stratigraphy, can be presented in ways that have cultural relevance for a Native community. The example comes from the Native American community of Acoma Pueblo in New Mexico. The first author is a member of this community and grew up on the Acoma reservation. The intent of this paper is to motivate fellow earth-science faculty and teachers to explore how their research specialties can be put into cultural terms that are beneficial for a Native community. While geologic concepts are universal, cultural concepts are specific. Our approach, therefore, requires efforts to develop an understanding of a person's culture in order to effectively communicate geologic concepts to that individual (e.g., Semken, 2005). Our example of integrating traditional knowledge (culture) and Western science is specifically for the tribal community of Acoma Pueblo, but the general approach that we advocate is applicable to other indigenous and land-based communities (e.g., Riggs, 2005).

Acoma Pueblo is a National Historic Landmark and is the oldest continually inhabited village in the United States. Generations of Acoma people have lived atop the mesa in west-central New Mexico making pottery, building their homes out of rock and mud, and farming the land at the base of the mesa. The Acoma community is literally embedded in the stratigraphy of the eastern Colorado Plateau. Knowledge of specific rocks and their uses has been passed on between generations for thousands of years. Few non-Native scientists, however, have interacted with the Acoma community and so no connection exists between the Western concept of stratigraphy and the cultural framework of the Acoma community.

Figure 1 is an example of educational material that connects the local stratigraphy (lithologies, thicknesses, and stratigraphic relationships) with Acoma cultural uses of specific geologic formations. The Western scientific viewpoint is represented by the stratigraphic nomenclature used by geologists to differentiate specific formations and their depositional environments (Fig. 1A). The Acoma Pueblo community member's perspective of the local stratigraphy is represented in terms of cultural uses of specific intervals of the stratigraphy (Fig. 1B). Instructors can use this figure to illustrate the Western scientific concept of stratigraphy/depositional environments and immediately link this information to traditional Acoma cultural knowledge and uses of different geologic materials. After the student/community member recognizes a stratigraphic horizon with implications for the community (e.g., the formation used in the construction of their homes—the Dakota Sandstone), our intent is that they will begin to recognize the same stratigraphic horizon and its potential use in different parts of the reservation. This recognition, in turn, develops the Western scientific concept of stratigraphic correlation.

Such usage would be an example of place-based education (PBE), which has been successful as a framework for teaching

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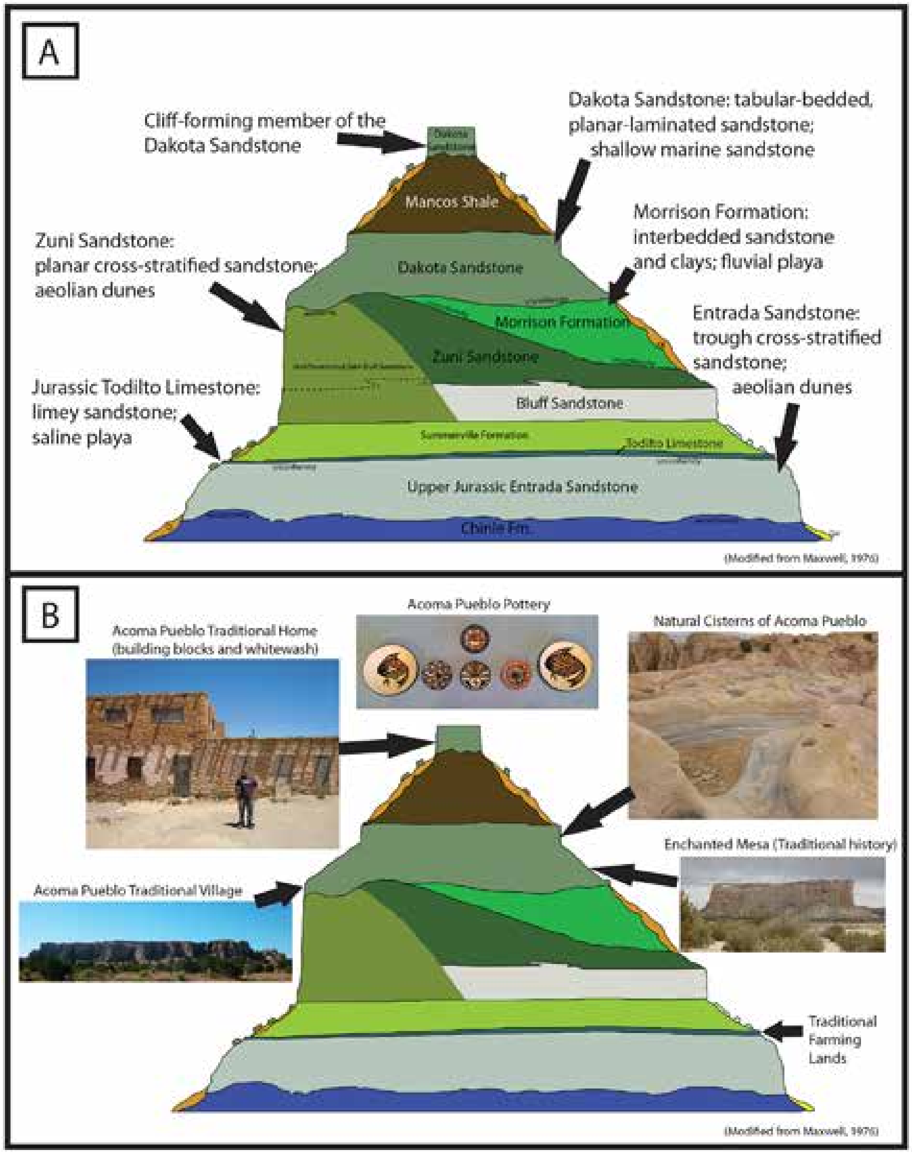

Figure 1. A comparison of the perspectives of Western earth sciences (A) and the Acoma Pueblo community (B) of the stratigraphy near Acoma Pueblo. The stratigraphic positions of earth materials that are "culturally sensitive" to the local Native communities have not been labeled in this version of the figure, because it is intended for non-tribal members. Modified from Maxwell (1976).

students from widely variable backgrounds about geologic concepts (Gruenewald, 2003; King, 2008; Semken et al., 2009; Semken and Brandt, 2010). Because PBE uses a holistic perspective, it is an effective way to combine scientific knowledge—which the student may be unaware of—with knowledge that is already within the student's realm of cultural awareness (Barnhardt and Kawagley, 2005). For our approach, we define PBE as an educational framework that can utilize landscapes/places as mediums through which cultural traditions and Western science inform each other through the lives of people as they experience these places.

Our approach builds on the educational framework that situates learning (knowledge) in the social context of the community, the tools and practices employed, and the activity itself (e.g., Lave and Wenger, 1991). For our example, PBE requires the blending of two cultures: that of the Acoma Pueblo people and that of Western science. We feel this blending of two cultures is an especially important element of teaching earth science to Native communities. In our version of this place-based pedagogy, the instructor provides an opportunity for the student to integrate Western scientific concepts with cultural knowledge that has already been socially transferred to the student from the elders and local community. This approach, which we advocate in this article, requires earth-science instructors to put their science into a cultural perspective, which in turn requires the instructors to become familiar with their local Native communities as well as Native perspectives and uses of the local landscape. During this phase of information gathering, respect for cultural boundaries (including consent to use the traditional knowledge for teaching purposes) should be paramount. Many times, this can be achieved through close collaboration with respected Elders as well as the governing entities of particular Native communities. Building these types of relationships requires time and trust, but they can also be very rewarding and provide learning opportunities for both the students and the instructor.

In closing, it is important to note that STEM education designed for the diverse cultural needs of Native American students is lacking. The future of these students' traditional communities is partially dependent on the strength of knowledge the community has regarding landscape uses, natural resources, geoengineering, climate change, and other aspects of earth science. The example we have presented demonstrates how to relate the concept of stratigraphy, a Western scientific construct, to the everyday lives of the Acoma Pueblo people. We contend that many similar connections between Western earth science and traditional indigenous knowledge wait to be developed with Native communities.

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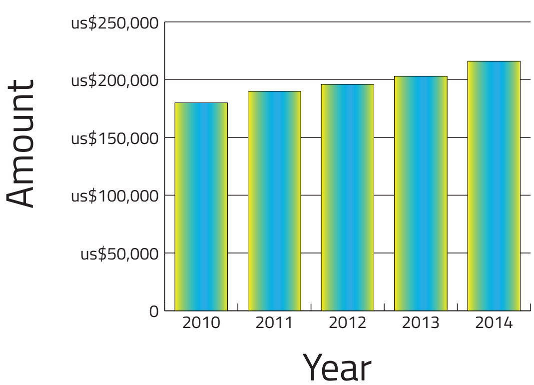

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