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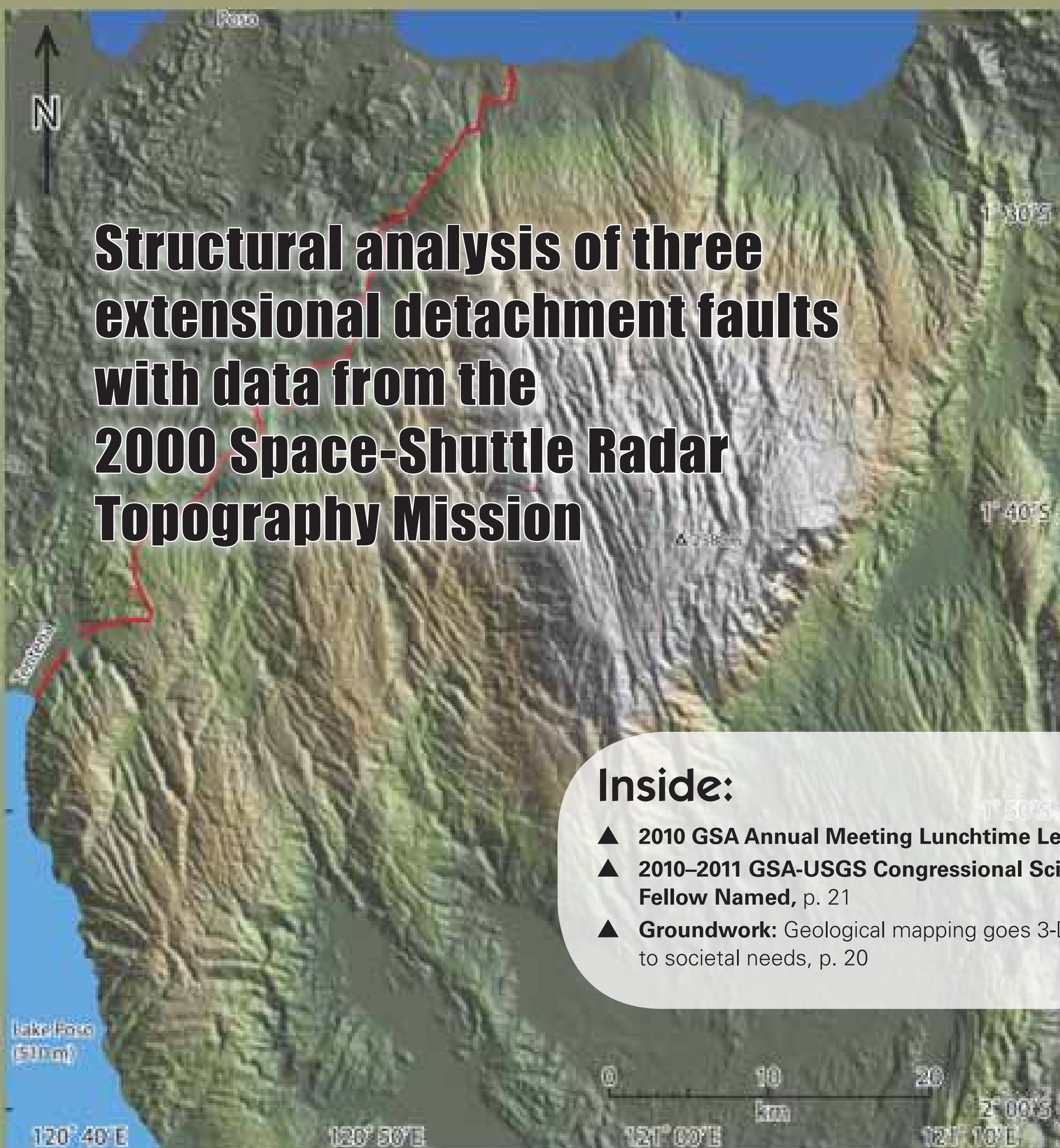

Structural analysis of three extensional detachment faults with data from the 2000 Space-Shuttle Radar Topography Mission

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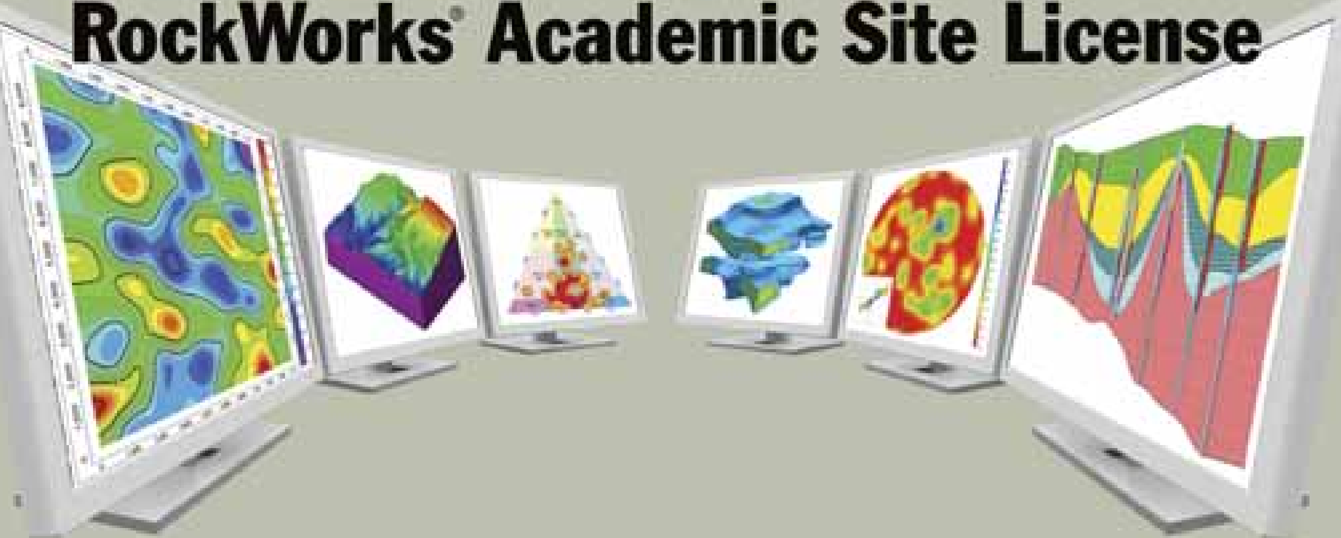

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SCIENCE ARTICLE

Cover: Shaded, false-color topography in part of central Sulawesi, Indonesia, derived from digital-elevation data from the 2000 Shuttle Radar Topography Mission. Red line across upper left indicates inferred, gently northwest-dipping extensional detachment fault. The striated Pompangeo crystalline complex that forms the massif in the center of the image is suspected to be a metamorphic core complex exhumed by tens of kilometers of displacement on the detachment fault. The unusual lineated topography is apparent at more detailed scale (e.g., aerial photo in Hamilton [1979, USGS Prof. Paper 1078, Fig. 86] of area indicated by magenta corners). See "Structural analysis of three extensional detachment faults with data from the 2000 Space-Shuttle Radar Topography Mission" by J.E. Spencer, p. 4–10.

Structural analysis of three extensional detachment faults with data from the 2000 Space-Shuttle Radar Topography Mission

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ABSTRACT

The Space-Shuttle Radar Topography Mission provided geologists with a detailed digital elevation model of most of Earth's land surface. This new database is used here for structural analysis of grooved surfaces interpreted to be the exhumed footwalls of three active or recently active extensional detachment faults. Exhumed fault footwalls, each with an areal extent of one hundred to several hundred square kilometers, make up much of Dayman dome in eastern Papua New Guinea, the western Gurla Mandhata massif in the central Himalaya, and the northern Tokorondo Mountains in central Sulawesi, Indonesia. Footwall curvature in profile varies from planar to slightly convex upward at Gurla Mandhata to strongly convex upward at northwestern Dayman dome. Fault curvature decreases away from the trace of the bounding detachment fault in western Dayman dome and in the Tokorondo massif, suggesting footwall flattening (reduction in curvature) following exhumation. Grooves of highly variable wavelength and amplitude reveal extension direction, although structural processes of groove genesis may be diverse.

INTRODUCTION

The February 2000 Shuttle Radar Topography Mission (SRTM) aboard the *Endeavour* acquired synthetic aperture radar data used to produce a new digital elevation model (DEM) of almost all Earth land areas between 60°N and 56°S latitude (Farr et al., 2007). The DEM is presently available for the entire survey area at 90 m spatial resolution (i.e., an elevation measurement is associated with each 90 m × 90 m area on Earth's surface). Heavily forested areas increase measured elevations because microwaves at the radar wavelengths are reflected by dense vegetation, and steep slopes produce local radar shadow zones with no data (Farr et al., 2007). Despite these problems, the new DEM provides very high-quality topographic data for 80% of Earth's land, much of which was not well surveyed before SRTM data acquisition and reduction.

The SRTM DEM is included in a global representation of bathymetry and topography maintained and upgraded by the Marine Geoscience Data System (MGDS) at Columbia University's Lamont-Doherty Earth Observatory. This global data set can be readily viewed online with the GeoMapApp© data visualization and analysis toolbox that is also available online from the MGDS at www.geomapapp.org. This Java™ application allows users to view topography and bathymetry at different map scales, create cross sections, and save the images as graphics files. Elevations are represented by color, contours, and shaded relief, all of which are adjustable through the graphical user interface.

Domal, planar, and grooved surfaces, clearly visible in images derived from the SRTM DEM, are associated with some active or recently active low-angle normal faults. Some of these surfaces form remarkably smooth topography over tens to hundreds of square kilometers in regions otherwise deeply incised by rapid erosion. In this article, I present images of three of the most spectacular examples and evaluate some of the structural, tectonic, and geomorphic processes associated with inferred fault-footwall exhumation.

DAYMAN DOME, PAPUA NEW GUINEA

Dayman dome of the Suckling-Dayman massif in eastern Papua New Guinea is the westernmost metamorphic core complex in an east-west–trending belt that includes the D'Entrecasteaux Islands in the Solomon Sea (Fergusson, Goodenough, and Normanby Islands on Fig. 1A). Active extension is associated with westward propagation of the Woodlark spreading center (Fig. 1A; Martínez et al., 1999) following middle to late Tertiary accretion of a Paleogene island arc (Davies and Jaques, 1984; Davies and Warren, 1988). Subduction of the leading edge of the Australia–New Guinea passive continental margin beneath the island arc was followed by tectonic extension and exhumation of ca. 4 Ma eclogite and ca. 8 Ma coesite-eclogite in the D'Entrecasteaux Islands (Baldwin et al., 2004, 2008). These high-pressure and ultra–high-pressure metamorphic rocks are associated with domal and corrugated mylonitic shear zones and normal faults that are characteristic of core complexes (Davies and Warren, 1988; Hill et al., 1992; Little et al., 2007).

Most of Dayman dome consists of variably metamorphosed and deformed basaltic rocks and less-common limestone interpreted to be part of the subducted oceanic crust that was originally outboard of the early Cenozoic passive continental margin (Davies, 1980; Davies and Jaques, 1984). The extensional detachment fault (Mai'iu fault) at the north foot of Dayman dome is associated with greenschist-facies metamorphism in footwall rocks and a strong, tectonite fabric that is also domed (Davies, 1980). The tectonite fabric at the north foot of the dome is a lineated mylonitic shear zone with north-northeast–plunging lineations and normal displacement (Daczko et al., 2009). Mineral equilibria modeling suggests deformation at depths >20 km (Daczko et al., 2009). A 016° direction of extension is inferred from the average trend of 169 measured outcrop-scale lineations (Caffi, 2008), and is essentially parallel to the ~019° axis

GSA Today, v. 20, no. 8, doi: 10.1130/GSATG59A.1

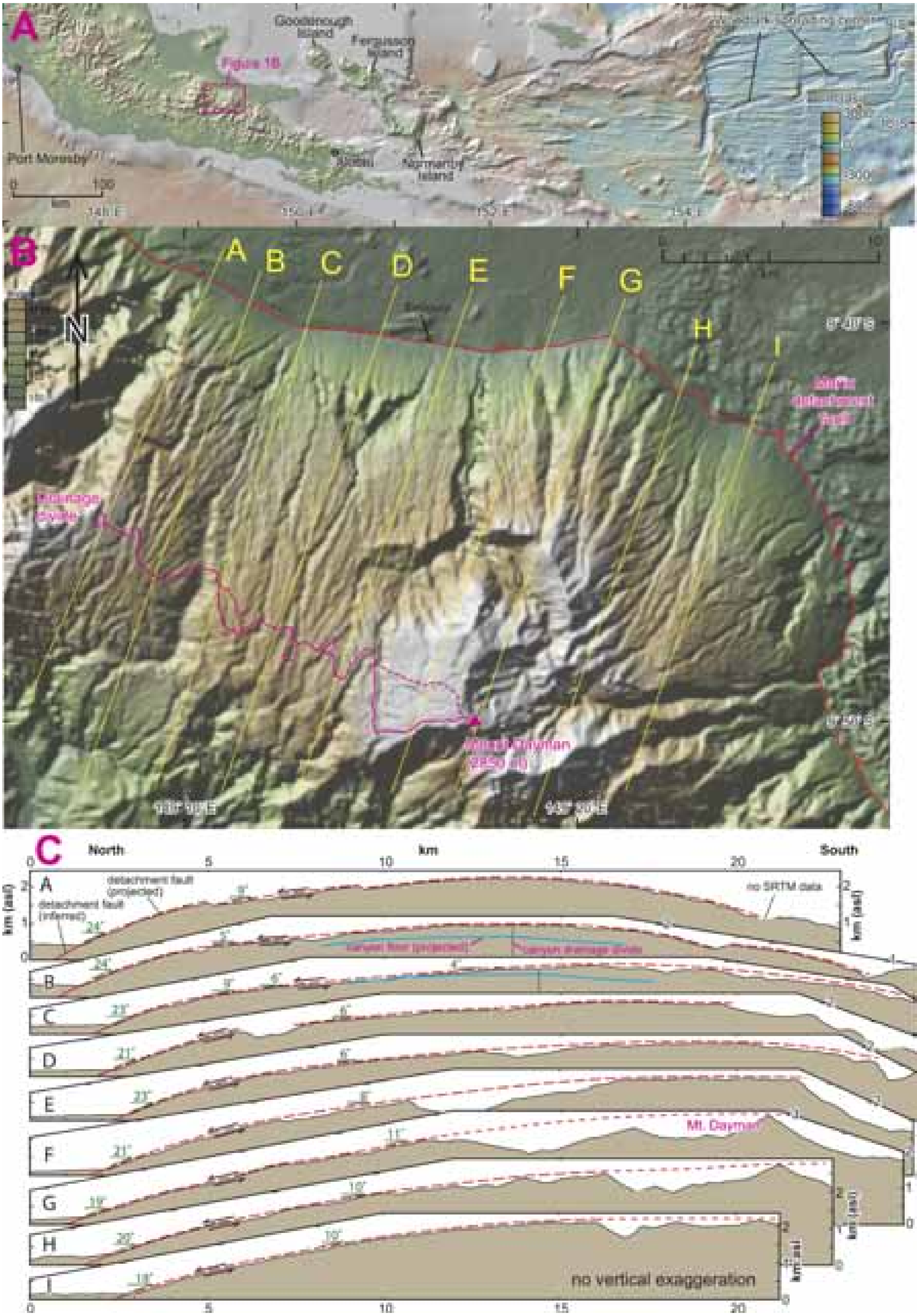

Figure 1. Elevation and shaded-relief maps and topographic cross sections derived from the Shuttle Radar Topography Mission (SRTM) digital elevation model using GeoMapApp©. (A) Map of Owen Stanley peninsula and D'Entrecasteaux Islands of easternmost Papua New Guinea, and Woodlark basin, with bathymetry derived from the Marine Geoscience Data System bathymetry database. (B) Map of Dayman dome (see Fig. 1A for location) showing trace of Mai'iu detachment fault (double ticks on hanging wall). Dashed lines are alternative locations for the drainage divide that are related to uncertainty in stream-flow paths at critical locations. (C) Topographic cross sections of Dayman dome (locations in B).

of the antiformal groove in northeastern Dayman dome (antiform axis coincident with cross-section line G in Fig. 1B).

The smooth form of Dayman dome (Fig. 1B) is readily interpreted to be due to rapid and geologically recent tectonic exhumation from beneath an active normal fault (Ollier and Pain, 1980, 1981). Most drainages are highly linear and trend down the local slope of the dome. Six drainages in the northeastern part of the dome, located between cross-section lines G and I on Figure 1B, trend subparallel to the ~019° extension direction rather than locally down slope. The orientation of these drainages is plausibly due to a process by which stream channels in the hanging-wall block guide the lengthening streams as they are incised into the freshly denuded footwall (Spencer, 2000; Spencer and Ohara, 2008). This process is similar to the displacement-parallel elongation of stream channels that are cut and offset by strike-slip faults.

The fault ramp at the north foot of Dayman dome dips 18° to 24° in the direction of hanging-wall displacement (Fig. 1C). Western cross sections reveal greater fault dip at the foot of the dome (Fig. 1C) and greater curvature over the northern 5 km of the dome (Fig. 2, Dayman B and C vs. H and I). Greater curvature in western areas and flattening at higher elevations appear to be due to concave-downward bending during and/or immediately following tectonic exhumation, followed by unbending at higher elevations. Such behavior is consistent with the "rolling hinge" model for core-complex exhumation under conditions of low flexural strength (Wernicke and Axen, 1988; Buck, 1988) and may be the clearest example of such behavior in an active continental core complex.

A remarkable geomorphic feature revealed by SRTM data is a canyon, located between cross sections B and C in Figure 1B, that crosses the drainage divide at the crest of the antiformal western part of Dayman dome. South of the pass that divides the canyon, the stream bed plunges 4°S over 3 km, whereas north of the pass, the stream bed plunges 1.2°N over 4 km, at which point it steepens and enters its very slightly incised lower reach (Fig. 1C, cross sections B and C). The simplest explanation for the origin of this canyon is that uplift and arching of western Dayman dome split a previously incised, north-flowing stream in two, thus reversing the drainage direction of the now south-flowing part of the canyon (Spencer and Ohara, 2008). The abrupt 5° change in streambed plunge across the pass suggests that there has been some period of stability in the position of the drainage divide and that there has not been a recent transfer of an essentially horizontal reach of the northern stream channel to the southern stream channel. However, given ongoing uplift at the northern margin of the dome and the gentle 1.2° plunge of the upper stream bed north of the pass, transfer of a 4 km reach of the northern drainage to the southern drainage seems feasible if not likely in the geologic near future.

GURLA MANDHATA, HIMALAYA

The Gurla Mandhata massif is one of the larger gneiss domes along the backbone of the Himalayan orogen (e.g., Hodges, 2000; Fig. 3A). The massif is bounded to the west by the late Cenozoic Gurla Mandhata detachment fault that juxtaposes Tethyan Himalayan Paleozoic strata and Tertiary sedimentary rocks with footwall mylonitic schist, marble, granitoids, and gneiss, with total offset estimated at ~30–70 km, directed toward 280° (Murphy et al., 2002). Detachment-fault displacement and extension have been interpreted as part of a dilational jog at the southeast end of the right-lateral Karakoram fault (Fig. 3A; Searle, 1996; Murphy et al., 2002).

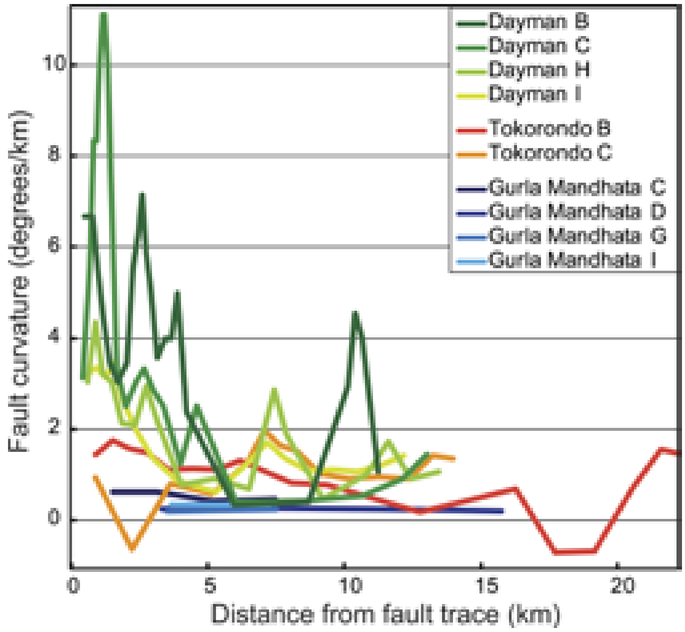

Figure 2. Fault curvature along selected displacement-parallel topographic profiles of three known or inferred detachment-fault footwalls. The spikes and troughs, especially apparent in the Dayman B cross section, result at least partly from differential erosion, where spikes represent subtle but developing ridges and troughs represent incipient stream valleys.

A shaded relief map of the west side of the Gurla Mandhata massif (Fig. 3B) clearly reveals the extensive, generally westward-dipping fault ramp structurally below the detachment fault. A 4-km-long, 400-m-wide groove trending 284° is apparent in the detachment-fault ramp north of the town of Kejia (Figs. 3B and 3C). Groove depth decreases eastward from ~30 m in cross section J1 to ~8 m in cross section L1, beyond which the groove vanishes. Murphy et al. (2002, Figs. 2 and 7A therein) mapped a south-side–down normal fault approximately coincident with the groove. However, cross sections derived from SRTM data indicate that the groove is not simply a step in the fault ramp, but a smooth, two-sided furrow (Figs. 3B and 3C). Furthermore, examination of the Kejia groove with satellite imagery (using Google Earth) reveals numerous linear features that parallel the groove. I conclude that the Kejia groove and associated, more subtle grooves that are barely discernable on SRTM imagery (Figs. 3B and 3C) reflect the grooved form of the footwall ramp and that finer-scale lineation in color and landforms revealed by satellite imagery is likely due to parallel linear fabric elements within footwall tectonites ("mylonitic schist" of Murphy et al., 2002, Fig. 7A therein). Accordingly, the 284° trend of the Kejia groove is used here to indicate detachment-fault displacement direction, which is nearly identical to the 280° ± 4° trend of stretching lineations measured in footwall mylonites of the Gurla Mandhata massif by Murphy et al. (2002).

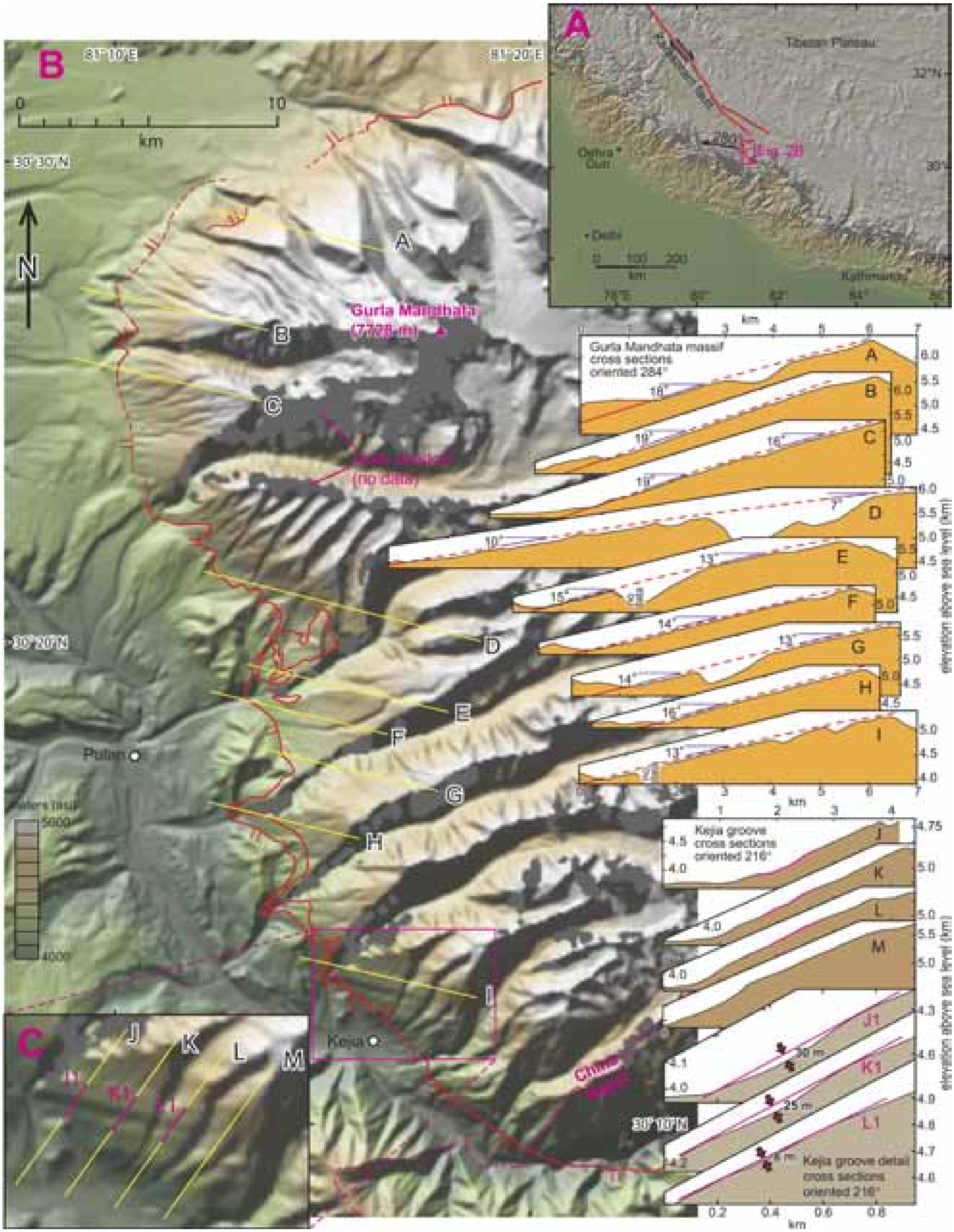

Figure 3. Elevation and shaded-relief maps and topographic cross sections derived from the Shuttle Radar Topography Mission digital elevation model using GeoMapApp©. (A) Map of the central Himalaya and southwestern Tibetan plateau. (B) Map of the west side of the Gurla Mandhata massif (location in A) and topographic cross sections (no vertical exaggeration). Faults (red lines, double ticks on detachment-fault hanging wall) from Murphy et al. (2002). (C) Close-up map of Kejia groove showing location of cross sections. Note that the 216° trend of the cross sections is not perpendicular to the 280° trend of the Kejia groove, but was chosen because it avoids intervening drainages that would obscure the cross-sectional representation of the groove.

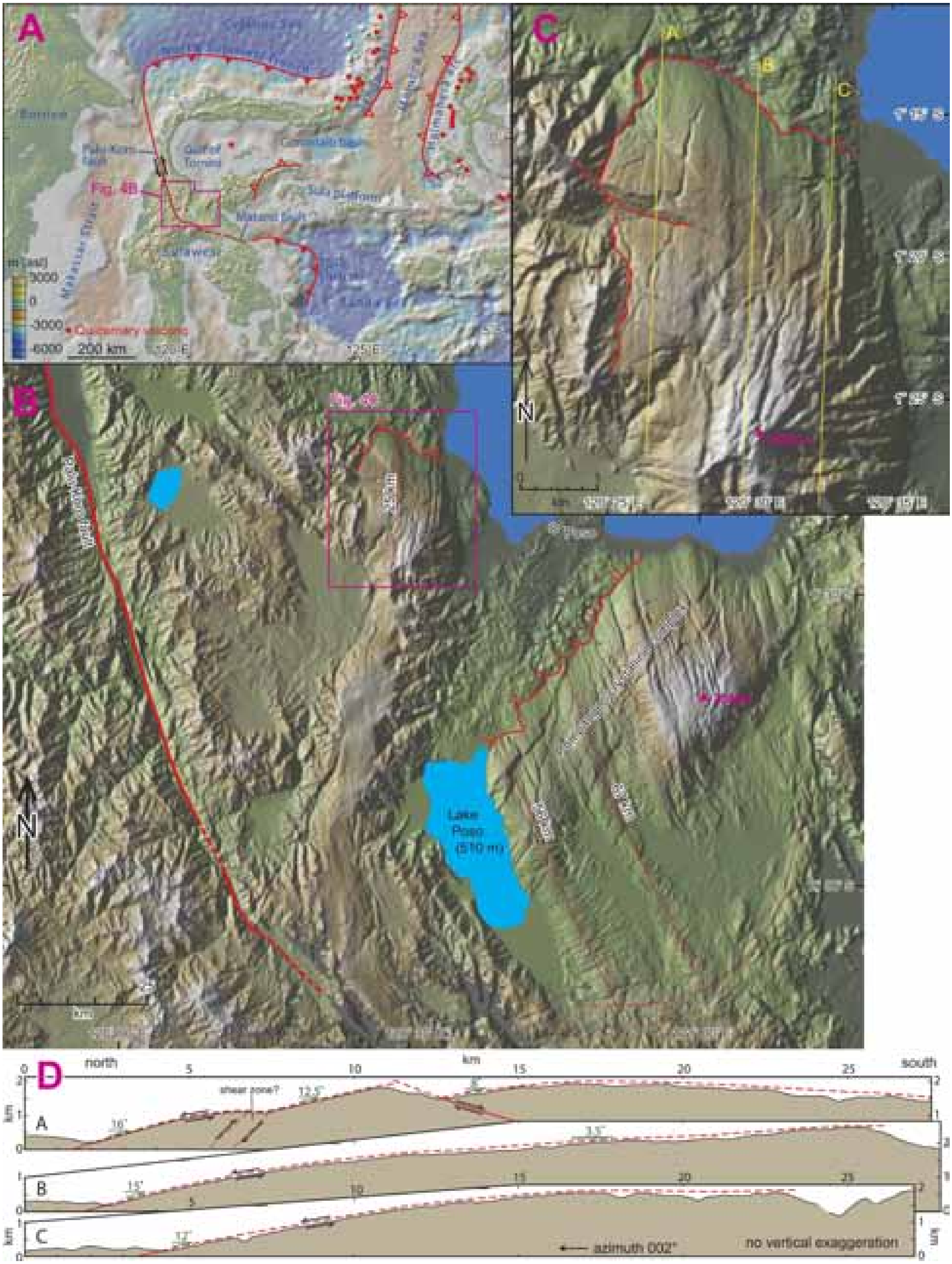

Figure 4. Elevation and shaded-relief maps and topographic cross sections derived from the SRTM DEM using GeoMapApp©. (A) Map of the Sulawesi and surrounding areas, with bathymetry derived from the Marine Geoscience Data System bathymetry database. Geologic features from Hamilton (1979) and Silver et al. (1983). (B) Map of central Sulawesi (location in A) showing inferred detachment faults (double ticks on hanging wall) and high-angle faults (red lines). (C) Map of the Tokorondo massif (location in B) showing inferred detachment fault and high-angle faults. (D) Topographic cross sections (location in C) of Tokorondo massif.

Nine topographic profiles of the detachment-fault footwall ramp on the west side of the Gurla Mandhata massif, all oriented parallel to the 284° trend of the Kejia groove and inferred fault-displacement direction (Fig. 3, cross sections A–I), reveal the low-curvature cross-sectional form of the fault ramp in this profile orientation. The component of fault dip (i.e., apparent dip) in the extension direction along profile D (Fig. 3), which is the longest cross section, changes only ~3° over 11 km. This contrasts with Dayman dome, where much higher curvature could reflect lower flexural strength in footwall rocks during tectonic exhumation (Fig. 2).

Also apparent in cross sections A–I is variation among cross sections in extension-parallel fault dip. The fault ramp in the area directly west of Gurla Mandhata dips 18°–19° in the 284° direction (cross sections A–C), whereas to the south, within a synformal megagroove in the detachment fault, groove-parallel fault dip is 10° or less (cross section D). If map-view extension direction is consistently parallel to the Kejia groove along the west flank of the massif (or to some other extension vector), then uplift paths of different parts of the footwall must be different, with the area west of Gurla Mandhata ascending more steeply than areas to the south. Such behavior would result in an increase in the surface area of the detachment fault over time. Alternatively, map-view extension direction varies across the massif, perhaps with footwall displacement vectors converging slightly toward antiforms, such as Gurla Mandhata, and away from flanking, lower-lying areas. Either possibility might have observable consequences in footwall rocks. For example, convergent flow of footwall rocks toward Gurla Mandhata should have produced slightly radial lineations.

TOKORONDO MASSIF, SULAWESI, INDONESIA

The active tectonics of eastern Indonesia are among the most complex on Earth. The region is a plate-tectonic triple junction that accommodates convergence between the Pacific, Eurasian, and Indo-Australian plates, but in detail, the area is characterized by such features as colliding arcs and rotating microplates (e.g., Hamilton, 1979; Hall, 2002, 2008). Northward displacement of northern Sulawesi over the Celebes Sea floor along a geologically young subduction zone has not yet been sufficient to initiate arc magmatism (Fig. 4A; Silver et al., 1983). The Palu-Koro left-lateral fault is linked to the North Sulawesi trench and accommodates northward movement of northern Sulawesi relative to the more stable interior of western Indonesia (Bellier et al., 2001). Features identified as extensional detachment faults in central Sulawesi are located east of the Palu-Koro fault and may be kinematically linked to it.

The topography of central Sulawesi as revealed by SRTM data is characterized by two large, corrugated landforms that are readily interpreted as the denuded footwalls of extensional detachment faults (Fig. 4B). Both domal landforms are corrugated on a scale of kilometers and both are bounded to the north by an abrupt transition to a region of completely different topographic character. The northern transitions are readily interpreted as gently north-dipping detachment faults.

The larger, southeastern corrugated landform, centered on the Pompangeo Mountains and extending over ~2000 km^2, consists primarily of marble, phyllite, quartz-mica schist, and metaconglomerate (Parkinson, 1998). Stretching lineations (n = 19) within strong transposition foliation approximately parallel the linear landforms (Parkinson, 1998, Fig. 5 therein). Both Hamilton (1979) and Parkinson (1998) attributed the lineated geomorphology to thrust imbrication, with thrusts striking parallel to the ridges. On the basis of geomorphologic similarity to Dayman dome, Spencer and Ohara (2008) interpreted the Pompangeo crystalline complex as the exhumed footwall of a detachment fault and suggested that the stretching lineations identified by Parkinson (1998) are products of mylonitic shearing during core-complex exhumation. The corrugated form of the crystalline complex extends southward to areas that were also possibly exhumed from below the detachment fault, suggesting as much as 60 to 70 km of extension (Fig. 4B).

The smaller corrugated massif, located west of Poso in the northern Tokorondo Mountains (Fig. 4B), is a lineated, elongate, gently north-plunging half-dome with a remarkably smooth surface covering ~300 km^2 (Fig. 4C). The sharp northern and western boundaries of the massif are interpreted to be a detachment fault (Fig. 4C). Three parallel grooves on the eastern side of the Tokorondo massif, spaced ~1 km apart and with crest-to-trough amplitude of a few tens of meters, extend along a 002° trend for ~12 km. These grooves, and more subtle grooves farther west on the massif (Fig. 4C), are interpreted as primary grooves in the detachment-fault footwall that reveal displacement direction. The small wavelength of the Tokorondo grooves, combined with their significant length, is characteristic of grooves on deep-sea rather than continental core complexes (e.g., Ohara et al., 2001). The groove-parallel extent of inferred footwall exhumation is at least 24 km (Fig. 4D, cross section B), indicating at least this amount of extension. In cross section (Fig. 4D), the overall curvature of the denuded fault footwall is intermediate between Dayman dome and Gurla Mandhata (Fig. 2), suggesting moderate flexural strength during exhumation. Decreasing curvature with distance from the northern edge of the exhumed footwall suggests flattening following exhumation (Figs. 2 and 4D, cross section B).

Two studies have concluded that central and northern Sulawesi are rotating clockwise about a point near the eastern end of the north arm of Sulawesi, with the Matano and Palu-Koro faults forming a small-circle transform boundary of the rotating block (Silver et al., 1983; Bellier et al., 2006; see also Soquet et al., 2006). However, analysis presented here of SRTM-derived images of central Sulawesi reveals what appear to be two large detachment faults that have potentially accommodated up to 100 km of north-south extension between northern and central Sulawesi. If interpreted correctly, the detachment faults indicate the need for a reappraisal of Plio-Quaternary kinematic models for the Sulawesi region.

CONCLUSIONS

Greater footwall curvature (in extension-parallel cross sections) and footwall flattening with displacement away from the flanking detachment fault, as are apparent at Dayman dome and in the central part of the Tokorondo massif (Fig. 4D, cross section B), suggest low bending strength, perhaps due to elevated geothermal gradients during subaerial exhumation. Footwall grooves are not obviously related to footwall curvature, however, as might be expected if groove genesis was associated with elevated footwall temperature and greater pliability. Furthermore, it is not known if the Tokorondo grooves were shaped by plastic processes while the Kejia groove was shaped by brittle processes, or if footwall composition (e.g., carbonate vs. quartzite) is important in groove genesis. It is clear, however, that SRTM data have provided geologists with a wealth of geomorphic information with which to investigate regions of active extensional tectonics and to outline issues for future field-based structural and thermochronologic investigations.

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LETTER

Dear Editor:

The Geological Society of America has been recognizing our best and brightest by three major awards: (1) the Penrose Medal, which was established in 1927 to recognize distinguished research in pure geology; (2) the Day Medal, which was initiated in 1948 for outstanding distinction in the application of physics and chemistry to the solution of geologic problems; and (3) the Donath Medal, which was endowed in 1988 to award scientists (35 years or younger) for outstanding achievement. Clearly, these are honorable objectives that we should all support for the good of the profession.

In the *Dialogue* article from the June issue of *GSA Today**, Jean Bahr (GSA President) and Jack Hess (GSA Executive Director) sounded an alarm regarding the future of these medals. They conveyed that the price of gold has become untenable; the 2.25 inch medals now cost US$6,000 each. This threatens to force a change from the customary 14-karat gold to gold-plated silver medals, or even presenting medals only when there are sufficient funds. These are drastic solutions. The world knows us as "the gold finders," and we should live up to it!

The alternative to dramatic changes to the original bequests is for GSA to receive at least US$270,000 to endow the medals for the foreseeable future. All we need now are "300 good men and women" to give US$1,000 each to this worthwhile cause. As I mail this, I am sending my contribution to the GSA Foundation†. It is hoped that similar contributions are made by 300 fellow geologists before the end of this year. I appeal to you to assure the continuation of this honorable practice.

Farouk El-Baz

Director of the Center for Remote Sensing and Research Professor in the Department of Electrical and Computer Engineering, Boston University; GSA member since 1961

Send letters to GSAToday@geosociety.org or Managing Editor, *GSA Today*, P.O. Box 9140, Boulder, CO 80301-9140, USA. Please keep your letter to 300 words or fewer; letters longer than 300 words will not be published. The *GSA Today* managing editor will edit letters for length and clarity. All letters will be forwarded to the *GSA Today* science editors for review before publication, and *GSA Today* reserves the right to reject any letter at the discretion of the science editor. Opinions presented do not reflect official positions of the Society.

*v. 20, no. 6, p. 11

† www.gsafweb.org; 3300 Penrose Place, P.O. Box 9140, Boulder, Colorado 80301-9140, USA

GSA MENTOR PROGRAM HIGHLIGHTS

MENTORING TOMORROW'S GEOSCIENCE LEADERS

The Geological Society of America runs two mentoring programs at its Section Meetings, 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 applied geology professionals.

These relaxed, small-scale programs provide a forum for undergraduate and graduate students interested in hydrogeology or applied geology as a career to participate in informal conversations over lunch with professionals currently practicing in these fields.

This season has been exceptional. After meeting with our mentors, some students were invited for interviews, while others created similar events at their own institutions. This spring, the Shlemon Program funds brought together 340 students and 45 mentors; the Mann Program linked 190 students with 20 mentors.

Both mentors and students leave these events expressing feelings of personal and professional growth. New friendships are made, and—to the students' good fortune—professional contacts are established for their future.

MENTOR COMMENTS

- "Thanks for the invitation to participate in this luncheon. I really enjoyed meeting the students … it was a win-win situation in my book!"
- "Thanks for the opportunity to visit with the students. I enjoyed it and hoped it helped them as well."
- "The students' questions were thought-provoking and they made me realize what a satisfying job I've got. I'd like to do this again!"

STUDENT COMMENTS

- "I am so excited to have been able to ask my questions!"
- "Very helpful to hear real world advice from professionals."
- "The mentors gave great advice about classes and skills to acquire for success."
- "The high mentor to student ratio of this program gives us time to ask all our questions and get great one on one advice."

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

The Roy J. Shlemon Mentor Program in Applied Geology

NORTHEASTERN/SOUTHEASTERN JOINT SECTION MEETING

Rebecca Beavers,
National Park Service

Mark Eisner,
Advanced Land and Water Inc.

Marjorie Gale,
Vermont Geological Survey

Sunny Rae Granger,
URS Corporation

Andrew Harrison,
Groundwater & Environmental Services Inc.

William Kelly,
New York State Geological Survey

Marian Lupulescu,
New York State Museum

Bill Matulewicz,
T&M Associates

Jennifer Miselis,
Naval Research Laboratory

Courtney Schupp,
Assateague Island National Seashore

Craig Sprinkle,
CH2M HILL

Gerry Stirewalt,
U.S. Nuclear Regulatory Commission

Marilyn Suiter,
National Science Foundation

Gregory Walsh,
U.S. Geological Survey

Arthur Zeizel,
Consultant

NORTH-CENTRAL/SOUTH-CENTRAL JOINT SECTION MEETING

Dick Berg,
Illinois State Geological Survey

Gregory Bratton,
Running Foxes Petroleum

Rex Buchanan,
Kansas Geological Survey

Ryan Choquette,
Tenaska Inc.

Douglas Gouzie,
Consultant and Missouri State University

Doug Melton,
Southwestern Energy Company

Andrew Phillips,
Illinois State Geological Survey

The Roy J. Shlemon Mentor Program in Applied Geology (*continued*)

David Powell,
Sunbelt Environmental Services Inc.

David Saja,
The Cleveland Museum of Natural History

Janine Sturdavant,
Shelby Resources LLC

Brandon Thornhill,
Environmental Works Inc.

David White,
Associated Electric Cooperative Inc.

ROCKY MOUNTAIN SECTION MEETING

John Biczok,
Goldcorp Inc.

Mike Brost,
Cameco Resources

Gary H. Haag,
U.S. Forest Service

Larry Jackson,
U.S. Army Corps of Engineers

Ashli Maddox,
U.S. Geological Survey

Lance Rom,
Quality Services Inc.

CORDILLERAN SECTION MEETING

Kirt Campion,
Marathon Oil Company

Margaret Gooding,
LSA Associates Inc.

Chris T. Higgins,
California Geological Survey

Terry Kloth,
DCCK Engineering Inc.

Robert (Bob) Pinotti,
Puget Sound Energy

Eric Scott,
San Bernardino County Museum

Joseph Senecal,
Occidental of Elk Hills Inc.

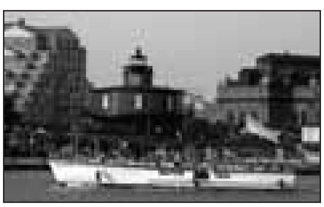
Kathleen Springer,
San Bernardino County Museum

Donald Sweetkind,
U.S. Geological Survey

Daniel J. Tearpock,
Subsurface Consultants & Associates LLC

Jennifer Thornburg,
California Geological Survey

Janet Tilden Watt,
U.S. Geological Survey



Photos from left to right: Baltimore's Inner Harbor; photo courtesy Visit Baltimore. Worm burrows; photo by Kevin R. Evans. Dinosaur Park (designed by Emmet Sullivan), Rapid City, South Dakota, USA; photo courtesy Rapid City Convention & Visitors Bureau. Orange County coastal sunset; courtesy http://static.panoramio.com/photos/original/3679706.jpg.

The John Mann Mentors in Applied Hydrogeology Program

NORTHEASTERN/SOUTHEASTERN JOINT SECTION MEETING

John Bratton,
U.S. Geological Survey

Judith Denver,
Maryland-Delaware-DC Water Science Center

Mark Eisner,
Advanced Land and Water Inc.

Rodney Sheets,
U.S. Geological Survey

Craig Sprinkle,
CH2M HILL

Arthur Zeizel,
Consultant

NORTH-CENTRAL/SOUTH-CENTRAL JOINT SECTION MEETING

Melinda Campbell,
Illinois State Geological Survey

Shiloh Kirkland,
Ozark Underground Laboratory Inc.

Robert Mace,
Texas Water Development Board

Edward Mehnert,
Illinois State Geological Survey

Susan Stover,
Kansas Water Office

ROCKY MOUNTAIN SECTION MEETING

P aula Cutillo,
National Park Service

Tessa Harden,
U.S. Geological Survey

Eric Harmon,
HRS Water Consultants Inc.

Jeffrey Hughes,
National Park Service

Aaron Larson,
South Dakota Department of Environment and Natural Resources

Robert Oaks, Jr.,
Classic Geological Studies Corporation

CORDILLERAN SECTION MEETING

Shelby Barker,
Kleinfelder

Greg Cranham,
Hargis + Associates Inc.

Anna Garcia,
Mojave Water Agency

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2011

NORTHEASTERN/ NORTH-CENTRAL
Joint Section Meeting
Pittsburgh, Pennsylvania, USA
20–22 March 2011
Abstract deadline:
14 December 2010

SOUTHEASTERN
Section Meeting
Wilmington, North Carolina, USA
23–25 March 2011
Abstract deadline:
14 December 2010

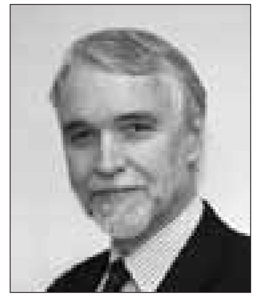
SOUTH-CENTRAL
Section Meeting
New Orleans, Louisiana, USA
27–29 March 2011
Abstract deadline:
18 January 2011

ROCKY MOUNTAIN/ CORDILLERAN
Joint Section Meeting
Logan, Utah, USA
18–20 May 2011
Abstract deadline:
15 February 2011

GSA Section Meeting Schedule

2010 GSA Annual Meeting & Exposition
Denver, Colorado, USA

Lunchtime Lectures



Timothy L. Killeen

GSA Lunchtime Lecture 2

Timothy L. Killeen: *Challenges and Opportunities across the Geosciences and Beyond*

Monday, 1 Nov., 12:15–1:15 p.m.

Timothy Killeen is assistant director for geosciences at the U.S. National Science Foundation (NSF), having taken on this role in 2008 through an Intergovernmental Personnel Act (IPA) assignment. Prior to joining the NSF, Killeen was director of the U.S. National Center for Atmospheric Research (NCAR) for eight years. Killeen still serves as senior scientist in NCAR's High Altitude Observatory, where his research interests include the experimental and theoretical study of Earth's upper atmosphere.

Before NCAR, Killen was professor of atmospheric and space science at the University of Michigan. During his tenure, he served as director of the University of Michigan's Space Physics Research Laboratory and as the university's associate vice president for research.

Killeen was born in Cardiff, Wales, and received a B.Sc. in physics and a Ph.D. in atomic and molecular physics from University College London. Killeen is past president of the American Geophysical Union (AGU), a Fellow of the American Meteorological Society (AMS), a former AMS Councilor, and a member of the National Academy of Engineering. He has served as president of AGU's Space Physics Section and on numerous NASA, NSF, AGU, and university committees. He was also co-chair of the NASA Sun-Solar System Connection Strategic Roadmap Committee and is a past editor-in-chief of the *Journal of Atmospheric and Solar-Terrestrial Physics*.

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GSA's Lunchtime Lectures series offers four one-hour presentations (one for each day of the meeting) by high-profile speakers on broad topics relevant to today's world. Bring your lunch and prepare to be challenged and inspired! Information on each speaker will appear in subsequent issues of *GSA Today* as well as on the meeting Web site, www.geosociety.org/meetings/2010/.

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Call for Applications and Nominations
GSA BOOKS SCIENCE EDITOR

GSA's internationally recognized books rely on the expertise of dedicated science editors who ensure stringent peer review, maintain excellent content, and provide leadership in determining the future course of GSA publications. GSA is currently soliciting co-editor applications and nominations for a books science editor. The four-year term begins July 2011. Duties include: soliciting and reviewing proposals for GSA Special Papers and Memoirs; evaluating peer-reviewed papers prepared for edited volumes to determine readiness for publication; coordinating peer review of single-author volumes; making accept or reject decisions for publication; and serving on the GSA Publications Committee on a rotating basis.

The successful candidate will be one who enjoys talking with potential authors and volume editors at meetings and conferences to develop ideas for volumes. Desirable characteristics include:

- a broad interest and experience in geosciences; international recognition;
- a progressive attitude, willingness to take risks and encourage innovation;
- familiarity with many earth scientists and their work;
- a sense of perspective and humor;
- organized and productive;
- willingness to work closely with GSA headquarters staff;
- ability to make decisions;
- familiarity with new trends in geosciences; and
- willingness to consider nontraditional research in geosciences.

Editors work out of their current locations at work or at home. GSA provides some funding for each position; for specifics on funding and expected workload, please contact Jeanette Hammann, +1-303-357-1048, jhammann@geosociety.org. If you wish to be considered, please submit a curriculum vitae and a brief letter describing why you are suited for the position. If you wish to nominate another, submit a letter of nomination and the individual's written permission and CV. Send nominations and applications to Jeanette Hammann, GSA Publications, P.O. Box 9140, Boulder, CO 80301, USA; jhammann@geosociety.org. Nominations or applications received by 15 September 2010 will be given first consideration.

Donna L. Russell, *Director of Operations*

GSA Foundation's Silent Auction at the GSA Annual Meeting in Denver

The GSA Denver meeting is right around the corner, and we hope you will make it a priority to visit the Foundation's 11th Silent Auction. The auction will once again be located at the GSA Foundation booth in the Exhibit Hall at the Colorado Convention Center.

Please stop by to see the many items up for bid. We'll have gift certificates for meals and hotels; ski passes; vacation/lodging packages; rock and mineral specimens; wine; jewelry; rare books; and many other items donated by Foundation supporters. The auction is a good place to find special holiday gifts and support the Foundation at the same time.

All money received goes into the Foundation's **Greatest Needs Fund,** which supports a multitude of programs, including research grants, student travel grants (domestic and international), education and outreach activities, and GSA publications.

The Exhibit Hall opens for the annual meeting welcoming party on Sunday, 31 Oct., at 6 p.m. and closes at 8 p.m. that night. We encourage early bidding! If you can't make it Sunday night, we'll be open during Exhibit Hall hours, 9 a.m.–6 p.m. Monday and Tuesday and 9 a.m.–2 p.m. on Wednesday. Come help us make our 11th Silent Auction a success—I look forward to seeing you there.

WOULD YOU LIKE TO DONATE TO OUR AUCTION?

You can donate practically any item to the auction, including fossils, mineral specimens, jewelry, rare geologic books or maps, wine, field supplies, antiques, timeshares, and gift certificates. Last year, bidders enthusiastically pursued timeshares from a variety of places around the country.

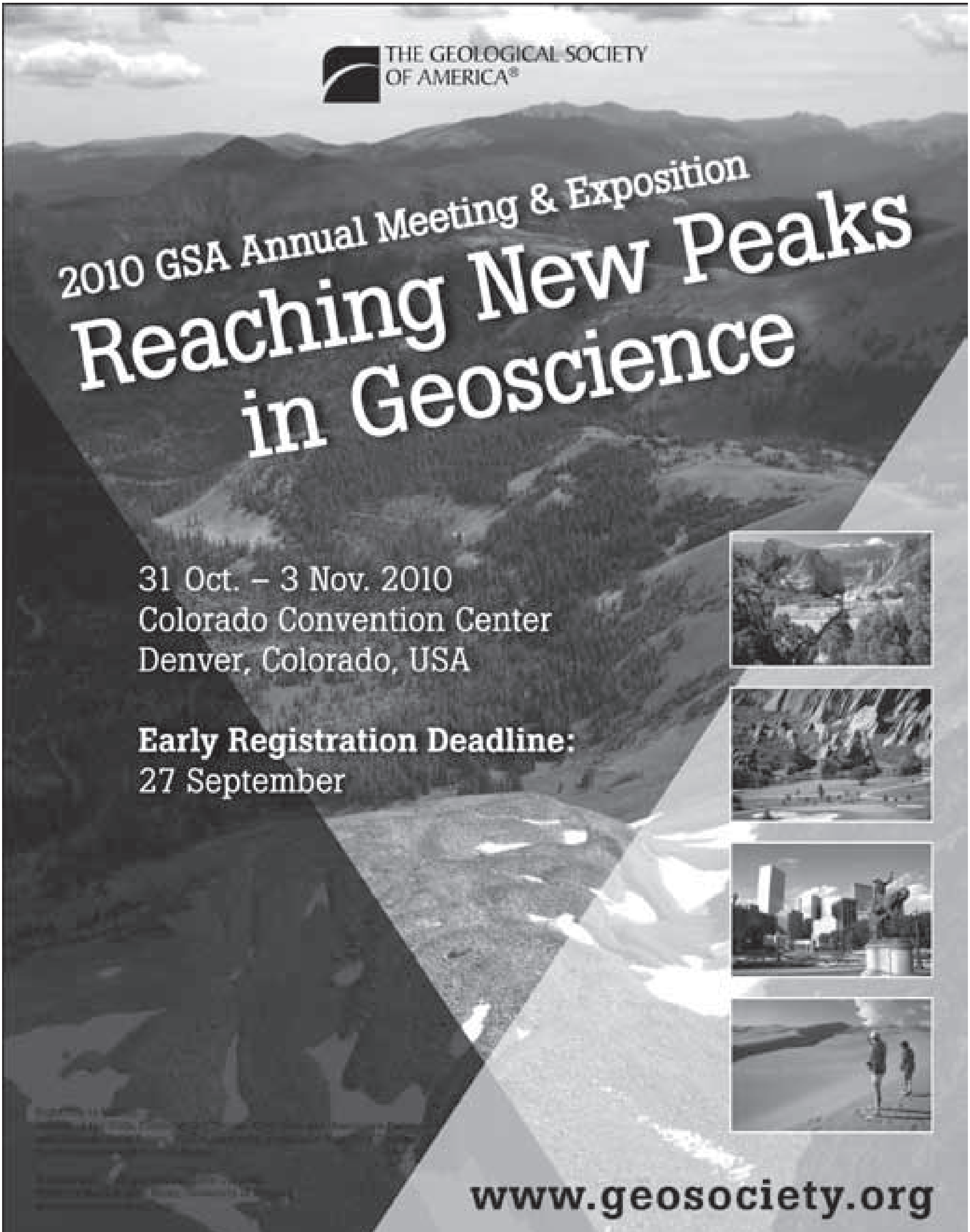
Your donation is tax deductible based upon its retail value. Your name will be listed as the donor on the auction item in the Foundation booth and on our Silent Auction Supporters poster. If you don't have anything for the auction, we're happy to accept a cash donation.

You may ship donations directly to the attention of Donna Russell or Geni Klagstad at the GSA Foundation, P.O. Box 9140, Boulder, CO 80301-9140, USA. For further information, please contact Donna at drussell@geosociety.org, +1-303-357-1054, or Geni at gklagstad@geosociety.org, +1-303-357-1010.

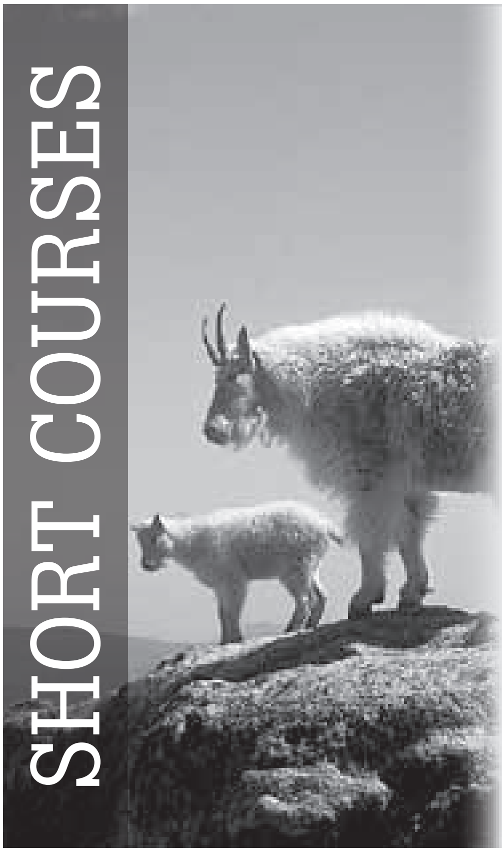
Most memorable early geologic experience:

The 1947 University of Wyoming summer field camp was my first real experience with geology. One day we were encouraged to scramble up a roadside bank to find Eocene mammal remains. I found none, but at the top of the bank there was the complete skeleton of a smallish animal. Convinced that I had made a major discovery, I asked the teaching assistant in the most insouciant manner I could muster to look at my great find. He obliged, looked at the skeleton, and said in a kindly way: "Dick, that squirrel died about six months ago." I decided, then and there, to forego a career in paleontology.

—H.D. Holland


THE GEOLOGICAL SOCIETY
OF AMERICA®
2010 GSA Annual Meeting & Exposition
Reaching New Peaks
in Geoscience
31 Oct. – 3 Nov. 2010
Colorado Convention Center
Denver, Colorado, USA
Early Registration Deadline:
27 September
www.geosociety.org

SHORT COURSES



2010 Short Courses are Moving Fast!

Short Courses at the GSA Annual Meeting fill up quickly, so we recommend you register as soon as you decide which course is right for you. Signing up early can also save you money: After 27 Sept., short course fees increase by US$30.

For full course descriptions, go to **www.geosociety.org/meetings/2010/courses.htm**; sign up for a short course at **https://rock.geosociety.org/registration/login.asp.**

All short courses offer continuing education credits (CEUs). If you have questions about this or about any of the short courses, please contact Jennifer Nocerino at jnocerino@geosociety.org.

PROFESSIONALS can attend a Gale software training session or learn more about field hydrogeology.

FACULTY topics span terrestrial laser scanning, geoinformatics, online volcano data monitoring, knowledge surveys, education research, plate tectonics, establishing undergraduate research programs, and teaching energy in the classroom.

GRADUATE STUDENTS will have the benefit of courses that address geographic information systems, sequence stratigraphy, seismic structural interpretation, and stratigraphic concepts applied to basin exploration.

K–12 TEACHERS will gain skills for engaging high school students in the geosciences.

Mountain goats photo used with permission from the Denver Metro Convention & Visitors Bureau.

GSA Today is Open Access Online

Go to **www.geosociety.org/pubs/** and click on the *GSA Today* cover.

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FUNDING for GSA's Research Grants Program

In 1933, R.V. Anderson received the first Geological Society of America research grant, using it to study the geology of the coastal Atlas Mountains in western Algeria. Seventy-seven years later, GSA's Research Grants Program is still growing and providing students with much-needed funding.

The **GEOSTAR** fund, created in 1987, augments the Research Grants Program. Contributions to GEOSTAR from individuals, industry, and institutions are vital—you can help support a young geoscientist's future by donating today.

Send your check to the GSA Foundation, 3300 Penrose Place, Boulder, CO 80301, USA; call +1-303-357-1054; or donate online at **gsafweb.org.**

GEOSTAR
Supporting The Advancement of Research

Red Rocks Amphitheatre. Photo by Bob Ashe for Denver Metro Convention & Visitors Bureau.

2010 Field Trips

Early registration deadline: 27 Sept.

GSA's 2010 "Reaching New Peaks in Geoscience" field trips cover a wide spectrum of geologic terrains and topics. Trips along excellent geologic exposures in the Colorado Rockies region will emphasize how glaciation, tectonism, volcanism, landslides, tectonic collapse, mineralization, and dinosaurs have shaped this region and how this geologic foundation influences hazards, resources, and human habitation.

This year's schedule ranges from local afternoon excursions to four-day regional adventures. One trip even calls for mountain bikes! Field trips are a great time to interact with colleagues, get out in the field, and even involve your family.

www.geosociety.org/meetings/2010/fieldTrips.htm

2010 Field Trip Co-Chairs
Lisa Morgan, lmorgan@usgs.gov
Steve Quane, steve.quane@gmail.com

Lawrence D. Meinert

2010–2011 GSA-USGS Congressional Science Fellow Named

GSA and the U.S. Geological Survey (USGS) are pleased to announce that Lawrence D. Meinert has been selected as the 2010–2011 GSA-USGS Congressional Science Fellow. He brings to the Fellowship a broad background in geoscience, ranging from the exploration, production, and genesis of ore deposits to the interplay of geological, biological, and agricultural practices in the making of fine wine. Meinert has published widely in these fields, including more than 150 peer-reviewed scientific articles on economic geology. He also co-edited a leading geological book on wine and terroir.

In addition to his own research, Meinert is active in academic publishing. He served as co-editor of *Mineralium Deposita*, the foremost European journal on natural resources, and is currently editor of *Economic Geology*—only the sixth editor in the 105-year publication history of this distinguished journal.

Meinert views the GSA-USGS Congressional Science Fellowship as a unique opportunity to link his experience in earth resources and scholarship to the policy-making arena. He expects that his diverse expertise and experience, including significant interaction with private business—ranging from large corporations to individual entrepreneurs—will help him to apply research discoveries to real-world problems. At a time when geological forces are increasingly visible in the news—from earthquakes to volcanic eruptions to oil spills to climate change—Meinert feels there is no better place to bring a geological perspective than the legislative and policy-making branches of the U.S. government.

Meinert's geological career started with a B.A. in geology from Carleton College, a Ph.D. in geology from Stanford University, and field work with ASARCO, Anaconda, and a variety of international exploration companies. Meinert has teaching and research experience at both Washington State University and Smith College. While at Washington State University, Meinert was a two-term chair of the faculty senate. In 2010, Meinert received the Silver Medal from the Society of Economic Geologists, the highest honor for mid-career scientists in this discipline. Among his serious hobbies are photography, running, and wine making.

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USGS
science for a changing world

EarthTrek Celebrates One-Year Anniversary

The Geological Society of America, along with more than 20 partners from science and industry, celebrated one year of "EarthTrekking" on 1 July 2010. EarthTrek is a worldwide initiative to connect the general public with scientists studying a variety of global, regional, and local topics by engaging communities in collecting much-needed field data. Along with reaping the benefits of the work of thousands of volunteers on the ground, EarthTrek aims to raise science literacy and encourage young people to pursue science careers by providing real science experience.

EarthTrek projects focus on environmental issues in which community involvement is the key to understanding the real nature of an issue at a local, regional, and/or global scale. Projects can come from any scientific field—botany, meteorology, atmospheric chemistry, physics, and biology, as well as earth science and beyond.

EarthTrek scientists maintain contact with project participants so that each participant knows how his or her work aids in the understanding of a problem or issue and how the data will be used in future decision making. Following protocols set by these scientists, individuals, families, clubs, or school groups are encouraged to trek into their environment and collect data, log that data online, and thus add to the pool of knowledge collected by other "EarthTrekkers" around the world. Participants also receive online incentives for their contributions by means of statistics records, certificates, and other rewards.

Three major projects are currently under way: The global *Gravestone Project* and *Garlic Mustard Field Survey* and the regional *Operation RubyThroat*.

GRAVESTONE PROJECT

This EarthTrek project involves data collection from graveyards around the globe. Participants measure the thickness of marble gravestones, or, if lead lettering was used, how far the marble has receded from the lettering. Using these measurements, scientists can create a worldwide map of how marble gravestones weather over time, which can provide insight into shifts in world pollution levels and climate change.

Image courtesy EarthTrek.

GARLIC MUSTARD FIELD SURVEY

It is widely believed that invasive species are larger, reproduce more, and reach higher densities than their native counterparts; surprisingly, however, relatively little hard data exist to support this claim. The Garlic Mustard Field Survey has participants identify and measure the location of garlic mustard, one of the most problematic invaders in North America. Scientists will use these data to compare garlic mustard's invasive spread across the planet with growth in its native Europe—research that will ultimately lead to better understanding and management of native species.

OPERATION RUBYTHROAT: THE HUMMINGBIRD PROJECT

Covering North and Central America, this project seeks to study the ruby-throated hummingbird. Although the ruby-throated hummingbird is the most widely distributed of the 339 species of hummingbird, many aspects of its natural history are not well understood; this EarthTrek project aims to gather data about the timing of ruby-throat migration as well as its nesting habits. Using these data, scientists aim to gain a more comprehensive understanding of ruby-throat behavior. Over time, participant contributions may help scientists determine whether these behaviors are changing, perhaps due to external factors such as climate change or habitat alteration.

Image courtesy D.W. Maiden, www.virginiabird.com.

www.goearthtrek.org

For more information, contact Gary Lewis, GSA Director of Education & Outreach at +1-303-357-1043 or glewis@geosociety.org.

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Classified Rates—2010

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	$8.85	$8.60
Opportunities for Students		
First 25 lines	$0.00	$4.50
Additional lines	$4.50	$4.50
Fellowship Opportunities	$8.85	$8.60

Positions Open

FACULTY POSITION IN BIOGEOSCIENCE
DEPT. OF EARTH & ENVIRONMENTAL SCIENCES
AND THE LAMONT-DOHERTY EARTH
OBSERVATORY
OF COLUMBIA UNIVERSITY

The Department of Earth & Environmental Sciences seeks applicants for a faculty position in biogeoscience at the tenure-track or tenured level. We seek applicants engaged in process-oriented research who will bring crucial new skills such as use of molecular-level tools, innovative remote sensing techniques, new insight or methodology for understanding biogeochemical cycles, specialist knowledge of ecosystem energetics, and/or application of nano-scale techniques. Our ongoing research in fields related to biogeoscience includes study of biogeochemistry and geochemistry, paleoecology, ecophysiology, climate and paleoclimate, oceanography and paleoceanography, geologic carbon capture and storage, fluid-rock interaction, and the human dimensions of environmental change. Preference will be given to strong applicants who can integrate their work within this spectrum.

Minimum requirements for the position are demonstrated scientific creativity, specialist knowledge in both biology and geoscience, a Ph.D. in a biogeoscience-related field, and the capability to teach at the undergraduate and graduate level. Application review will commence immediately and continue until the position is filled. For more information and to apply for this position please visit our online site at: **https://academicjobs.columbia.edu/applicants/Central?quickFind=53131**

Questions can be addressed to Peter Kelemen (peterk@LDEO.columbia.edu), Chair of the Search Committee.

Columbia University is an Equal Opportunity/Affirmative Action employer.

FACULTY POSITION, GEOLOGY DEPT
PETROLOGY/MINERALOGY
BRYN MAWR COLLEGE

The Dept. of Geology at Bryn Mawr College invites applications for a full-time, tenure-track Assistant Professor position to begin 1 July 2011 in the general areas of mineralogy/geochemistry/petrology. Applicants should demonstrate strong potential for excellent teaching and creative research as well as interest in offering courses in mineralogy, geochemistry, and petrology. The hire will be expected to participate in Bryn Mawr's interdisciplinary environmental studies program. The candidate's research specialty is open, but ideally will complement those of other faculty members at the College. Demonstrated teaching ability and a Ph.D. at the time of appointment are required, and a commitment to supporting women and underrepresented groups in the geosciences is desired.

Located in suburban Philadelphia, Bryn Mawr College is a highly selective liberal arts college for women who share an intense commitment to intellectual inquiry, an independent and purposeful vision of their lives, and a desire to make meaningful contributions to the world. Bryn Mawr comprises an undergraduate college with 1,300 students, as well as coeducational graduate programs in social work and in some humanities and sciences. The College promotes faculty excellence in both research and teaching and has strong consortial relationships with Haverford College, Swarthmore College, and the University of Pennsylvania. Bryn Mawr College is an equal-opportunity employer; minority candidates and women are especially encouraged to apply.

Applicants should submit a CV, a statement of teaching and research goals, a list of possible courses that could be offered, and the names and contact information of three references to Geology Search, Department of Geology, Bryn Mawr College, 101 N. Merion Ave., Bryn Mawr, PA 19010 (email contact: jjacoby@brynmawr.edu). Members of the Department will be available for preliminary interviews at the Geological Society of America meetings in October, and formal review of applications will begin on 15 November 2010. Details about the department are available at **www.brynmawr.edu/geology/.**

TENURE-TRACK POSITION
COLD REGIONS HYDROLOGY,
SCHOOL OF GEOGRAPHY & EARTH SCIENCES
MCMASTER UNIVERSITY

The School of Geography and Earth Sciences (SGES) at McMaster University in Hamilton, Ontario, Canada invites applications for a full-time tenure-track position at the Assistant Professor level beginning or at more senior level under exceptional circumstances beginning 1 January or 1 July 2011 in cold regions hydrology.

McMaster University is among leading Canadian universities with 24,000 full-time undergraduate and 3,000 graduate students. SGES has 29 full-time faculty members with more than a third of them focusing on water-related research. The Hydrological Sciences program of SGES has an excellent national and international reputation for research and teaching in cold-regions hydrology. For further information about the SGES please visit **www.science.mcmaster.ca/geo/.**

The successful candidate must have a Ph.D. in hydrology, physical geography or earth and environmental sciences at time of appointment. We are particularly interested in an individual with a strong background or research experience in physical hydrology and who undertakes field research in snow, ice and/or frozen ground hydrological processes. The candidate is expected to develop a well funded, externally recognized research program. The applicant should have a strong commitment to undergraduate/graduate teaching and supervision.

All qualified candidates are encouraged to apply; however, Canadians and permanent residents will be considered first for this position. McMaster University is strongly committed to employment equity within its community, and to recruiting a diverse faculty and staff. The University encourages applications from all qualified candidates including women, members of visible minorities, Aboriginal persons, members of sexual minorities, and persons with disabilities.

Applicants should send a cover letter outlining their research interests, a copy of their *curriculum vitae*, a brief teaching dossier including a statement of teaching philosophy (max. 2 pp.). These materials may be sent as hard copy or as a PDF file. Hard copies of no more than three published reprints or works in progress may also be sent to the Chair of the Search Committee by the closing date of 15 September 2010. Candidates are required to ensure that three referees send letters of recommendation to the Search Committee Chair by the closing date. Evaluation of files will begin on their receipt.

Dr. John Eyles, Chair, Search Committee, School of Geography and Earth Sciences, General Science Building, Room 206, McMaster University, 1280 Main Street West, Hamilton, Ontario, Canada - L8S 4K1. Tel: (905) 525-9140, ext. 23152 Fax: (905) 546-0463 Email: eyles@mcmaster.ca

FACULTY POSITION IN GEOSCIENCES
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 in the area of geosciences related to mineral resources. The candidate's research should be original and address significant geological, geochemical, or geophysical questions related to mineral resources and allied topics in fields such as petrology, tectonics, geochemistry, or geophysics. Approaches can be field, lab, or theoretical, and could involve settings from surficial to magmatic, scales from microscopic to global, and 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 successful candidate is expected to engage in multidisciplinary research and teaching through the Department of Geosciences, the partnerships and initiatives of the Lowell Institute for Mineral Resources and related professional programs, and the new School of Earth and Environmental Sciences. The position has been created as part of a campus-wide initiative on the sustainability of mineral resources with support from multiple state, federal, industry and non-governmental organizations.

In addition to completing the online application (UA Job Number 44141, **www.arizona.edu**), a cover letter, CV, and statement of teaching and research interests, please submit up to five reprints of published work and arrange for three letters of recommendation to be sent to The Economic Geology Search Committee, Department of Geosciences, University of Arizona, 1040 East 4th Street Tucson, AZ 85721-0077 U.S.A., or by e-mail to egsearch@email.arizona.edu.

The deadline for applications is 15 September 2010. We anticipate a start date in 2011.

VERTEBRATE PALEONTOLOGY LAB TECHNICIAN/PREPARATOR
CARTHAGE COLLEGE

Carthage College is seeking qualified applicants for the position of Vertebrate Paleontology Lab Technician/Preparator at the Carthage Institute of Paleontology. This is a full-time position that will require the Technician/Preparator to oversee the functions and activities of the Carthage Institute of Paleontology.

The Carthage Institute of Paleontology is housed in the Dinosaur Discovery Museum situated in Kenosha, Wisconsin. It is a federal repository for paleontological collections. The collections focus on specimens from the Hell Creek Formation of Montana. For additional information about the Museum, please visit **www.kenosha.org/dinosaurdiscovery/index.html.**

The technician/preparator will work under the direct supervision of the paleontologist, maintaining the lab and the specimens in it as well as providing instruction for students in the lab and field.

Qualifications: Master's degree with primary emphasis in sedimentology; demonstrated instruction of undergraduates in sedimentology in the lab and field; experience in the collection, preparation, molding, and casting of vertebrate fossils.

Situated on the Lake Michigan shore midway between Chicago and Milwaukee, Carthage offers quick urban access from a relaxed, small-city environment. More than ten million people live within a two-hour drive. Total college enrollment exceeds 3,000. Founded in 1847, Carthage is the fourth-oldest Lutheran college in the country.

Please submit letter of application, curriculum vitae, and three letters of professional reference to Thomas Carr, Carthage College, 2001 Alford Park Drive, Kenosha, WI 53140, tcarr@carthage.edu.

Deadline for Application: 16 August 16 2010.

BUREAU OF ECONOMIC GEOLOGY
JOHN A. & KATHERINE G. JACKSON SCHOOL OF GEOSCIENCES
THE UNIVERSITY OF TEXAS AT AUSTIN

The Gulf Coast Carbon Center (http://www.beg.utexas.edu/gccc/), an international leader in CO2 sequestration research, is looking for junior and senior geologists or engineers with expertise in reservoir characterization or reservoir fluid modeling. Previous experience in CO2 sequestration is desirable, but is not required.

- Reservoir Geologist/Petrophysicist (posting #100224030708)
- Reservoir Engineer/Fluid Flow Modelers (posting #100224040708)
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Please refer to the following website for a full description and requirements of each position, and to apply: **http://utdirect.utexas.edu/pnjobs/index.WBX**. Use the corresponding posting number for the position in which you are interested.

The University of Texas at Austin is an equal employment opportunity/affirmative action employer. All positions are security sensitive, and conviction verification is conducted on applicants selected.

TENURE TRACK ASSISTANT PROFESSOR PETROLOGY
CALIFORNIA STATE UNIVERSITY–NORTHRIDGE

The Department of Geological Sciences invites applications for a tenure-track position at the Assistant Professor level in the area of Igneous/Metamorphic Petrology and/or Geochemistry. The successful candidate must have a Ph.D. at the time of appointment. Experience in post-doctoral research and/or university-level lecture instruction is desirable. Particular subareas of interest that complement existing strengths in the department include, but are not limited to, volcanology, tectonomagmatism, mantle petrology, economic geology, and geochronology. The successful candidate is expected to develop a vigorous research program, which includes seeking extramural funding, publishing peer-reviewed papers, and involving undergraduate and M.S. students wherever feasible. Furthermore, the successful candidate is expected to demonstrate teaching excellence and provide effective instruction to students of diverse backgrounds in a multicultural setting. Instruction will include (1) undergraduate core courses in mineralogy and igneous & metamorphic petrology; (2) elective offerings at the upper-division and/or graduate level in the candidate's research specialty; and (3) courses in support of the Department's program in General Education and/or preparation of K–5 teachers in natural sciences.

Applicants should submit a cover letter, CV, three letters of recommendation, statement of teaching philosophy and experience, and statement of research interests. Electronic submissions are strongly encouraged and should be sent to geology.petrologist.search@csun.edu. Materials can also be sent to Petrologist Search Committee, Department of Geological Sciences, California State University Northridge, 18111 Nordhoff Street, Northridge, CA 91330-8266. Review of applications will begin 15 September 2010. Priority will be given to applications received by this date, but the position remains open until filled. For additional information, see **www.csun.edu/geology.** The University is an EO/AA employer.

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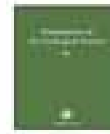

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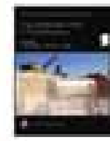

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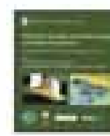

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GROUNDWORK

Furthering the Influence of Earth Science

Geological mapping goes 3-D in response to societal needs

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INTRODUCTION

In the early 1800s, state and federal geological survey agencies were conceived to address increasing demands for natural resource information to fuel the Industrial Revolution. More recent urbanization, however, has spurred surveys, along with their university and industry partners, to extend their applications from mining and energy to water supply, engineering, hazards, environment, and climate change, while more directly supporting the needs of decision makers.

Geological maps are at the heart of this decision support system. They are the method geologists use to synthesize and communicate an understanding of earth materials, processes, and history; however, for all geologic mapping, challenges remain in obtaining the information required to construct maps that are meaningful and helpful to users. This is particularly acute for subsurface mapping. Geologists must process data obtained through field work, geophysical surveys, and laboratory analyses and then compile that data to map the composition and distribution of materials in a format and resolution that serves map users. In turn, map users have an obligation to grasp the uncertainty of the map while providing the best possible service to their clients.

Previously, technological and data limitations dictated that a two-dimensional (2-D) paper map—accompanied by at most a few cross sections and a report—was the most appropriate publication format, so users were expected to infer subsurface conditions at their site. Over the past two decades, however, in response to demands for subsurface information in extensive areas of thick sediments and sedimentary rocks, 2-D geological mapping has been superseded by three-dimensional (3-D) mapping. Geological mapping thus has been redefined in these settings—from a single-layer 2-D map to a 3-D model showing thickness and properties of multiple stacked layers (Turner, 2003; Culshaw, 2006).

Having thus raised expectations among users for 3-D mapping, surveys and their partners are now seeking to rapidly improve their methods for construction, dissemination, and use of 3-D geological maps to support decision makers who must balance economic growth with environmental protection.

THE RISE OF 3-D GEOLOGICAL MAPPING

In the 1990s, surveys were under pressure in numerous jurisdictions, even threatened with closure or amalgamation, commonly due to their inability to communicate the value of geology to modern societies largely divorced from natural resource extraction. Surveys are now embracing both a resource and an environmental agenda, and a required element of this strategy is production of adequately detailed geological maps showing thickness and properties of strata, which are needed for applications such as groundwater modeling. For example, a 2000 U.S. National Research Council report (Committee on USGS Water Resources Research, 2000) called for better characterization of aquifers and their water resources. Concurrently, surveys are being called upon to produce similar assessments of carbon storage capacity, conventional energy, and geothermal energy, all of which require 3-D mapping.

The model for implementation of this sustainable development paradigm has varied. In the United States, the Great Lakes Geologic Mapping Coalition has produced 3-D mapping of the thickness of sand and gravel that is guiding a US$250-million-dollar water resource decision in northeastern Illinois. The coalition has also delineated a casting sand deposit in Michigan, leading to immense savings by the auto industry. The Canadian Framework for Collaboration on Groundwater is another example, and the British Geological Survey has developed a business model incorporating an institutional and national strategy on 3-D mapping (Howard et al., 2009). Other surveys have their own responses tailored to issues, political structures, and agency mandates.

The transition to 3-D mapping has been made possible by technological advances in digital cartography, GIS, data storage, analysis, and visualization (Whitmeyer et al., 2010). Concurrently, tools to assemble and manage large databases, such as drillhole data, have been adopted as part of a digital geological mapping business model. In the late 1990s, there was acceleration in our ability to work with innovative visualization methods, although these approaches presented challenges in cost, effort, and information exchange between varying, commonly proprietary software environments. Despite these challenges, technological advancements facilitated a gradual transition from 2-D maps to 2.5-D draped maps to 3-D geological mapping, supported by digital spatial and relational databases that can be interrogated horizontally or vertically and

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Figure 1. 3-D geological map of the 190-km-wide Fargo-Moorhead region of North Dakota and Minnesota, USA, constructed to clarify the context of regional groundwater systems (courtesy Minnesota Geological Survey).

viewed interactively. This evolution has taken us from depiction of a surface to specification of multiple layer thicknesses and properties.

Challenges associated with data collection, human resources, and information management are daunting due to their resource and training requirements. Nevertheless, reservations have been overcome by recognition of the urgency of emerging needs. In particular, the requirements of groundwater professionals have rendered 2-D maps insufficient; users now require the best available observations and predictions regarding thickness and properties of multiple strata so that they can model and manage water resources (e.g., Herzog et al., 2003) (Fig. 1).

The adoption of these methods has been charted over the past decade by six workshops[1] organized by the authors. Participants in the workshops have progressed from a realization that they are not alone in dealing with 3-D mapping issues to knowledge exchange that has evolved over the years from model construction methods to institutional workflows to online data delivery and to a comparison of national strategies.

The exchange of strategies at the workshops has highlighted the use of basin analysis to develop a process-based predictive knowledge framework that facilitates data integration (Sharpe et al., 2002). However, despite progress in technological advancements and a need for detailed geological information, there remains a woeful lack of necessary high-quality subsurface information, even in densely populated and industrialized nations. This continues to be a consistent theme for all mapping, and it highlights the importance of predictive geological models that can guide strategic data acquisition. Regardless of technological progress, a geologist's ability to conceptualize and visualize processes and events over broad spatial and temporal scales, and to predict material distributions into areas of sparse data, remains essential, as is well-planned coordination between geologists and modelers.

CONCLUSIONS

The progression from 2-D to 3-D geological mapping has demonstrated that surveys, working with their university and industry partners, are dynamic institutes that advance fundamental knowledge, that invent and utilize new technological opportunities, and that do what is required to optimize the quality of life enjoyed by the people in their jurisdictions. In this evolution of survey work, 3-D geological mapping has emerged as a natural progression—a direct result of both technological innovation and intensified land-use activity, especially in urban and suburban areas, transportation corridors, and environmentally sensitive regions. Three-dimensional geological information meets a public demand that fills in the blanks left by conventional 2-D mapping. Two-dimensional mapping will, however, remain the standard method for extensive areas of complex geology, particularly where deformed igneous and metamorphic rocks defy attempts at 3-D depiction. Nevertheless, for similarly large areas of undeformed sedimentary cover, where critical issues regarding sustainable land- and water-related decision making still exist, systematic subsurface information is required to guide economic development and environmental protection. Three-dimensional geological mapping directly addresses the need for improved subsurface depictions of materials and structures, as required for modeling by hydrogeologists, engineers, land-use planners, and industry.

Three-dimensional geological information is an essential technical requirement for addressing many current geoscience issues, while also being far more accessible to a wide audience. It allows land-use professionals, as well as the general public, to visualize their landmass as never before and enhances stakeholder understanding and subsequent engagement in planning and decision making. With this increased accessibility come mounting obligations for the producers of the information to convey uncertainty and to provide guidance to users. In addition, challenges remain in optimizing information delivery, particularly the Web accessibility now demanded by society. This rapid evolution in how surveys do business is essential to adequately respond to emerging issues. In seizing these opportunities and responding to these needs, geologists have changed our understanding of what a geological map can be, from a 2-D paper map to a 3-D multilayered model, which is now being seen as simply one form of geological map and now commonly the format that is readily achievable and most needed.

ACKNOWLEDGMENTS

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Manuscript received 3 Jan. 2010; accepted 17 May 2010.

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If you were a student or friend of Wayne's and would like to attend our celebration of his career, please contact **Todd Halihan at todd.halihan@okstate.edu** or OSU School of Geology, 105 NRC, Stillwater, OK 74078 for more information.

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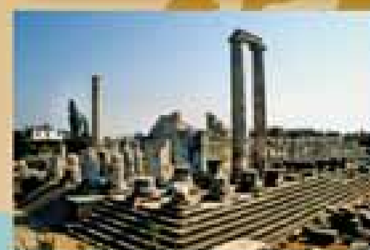

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