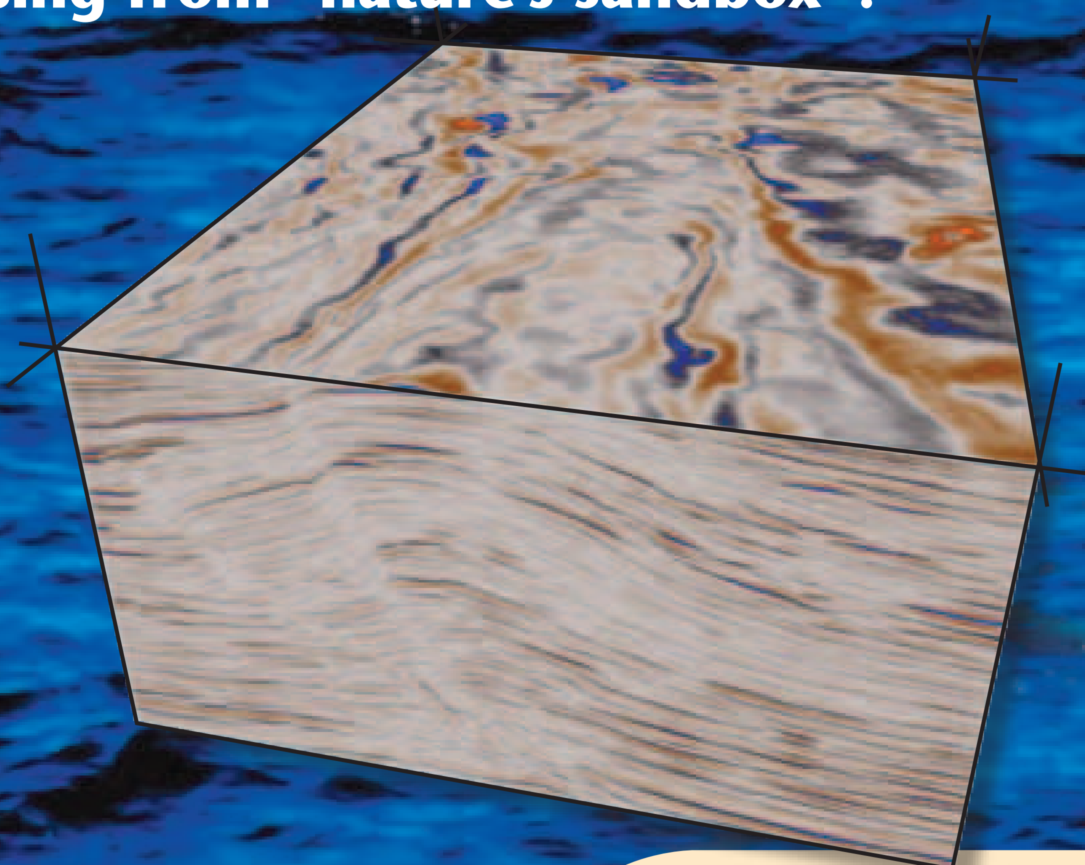
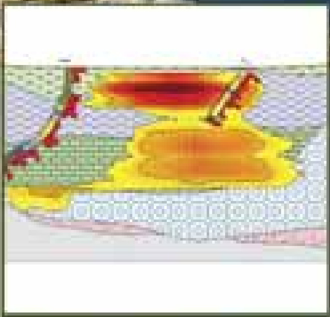
GSA TODAY

VOL. 20, No. 3 A PUBLICATION OF THE GEOLOGICAL SOCIETY OF AMERICA MARCH 2010

Evaluating lateral compaction in deepwater fold and thrust belts: How much are we missing from "nature's sandbox"?



Inside:



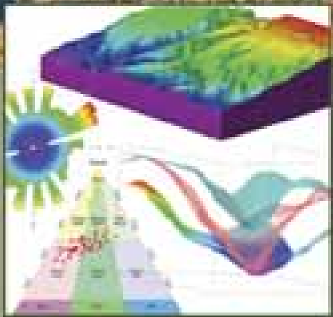
RockWorks®

Underground Data Management, Analysis & Visualization

- Streamlined well manager includes:
  - Deviated survey data
  - Lithology
  - Stratigraphy
  - Permeability, porosity, etc.
  - Oriented fractures
  - and more
- Interactively pick formation tops from raster e-logs
- Generate well logs, cross-sections, fence diagrams and stratigraphy models
- 2D (e.g. structure, isopachs) and 3D (porosity/permeability) contouring and volumetrics
- Includes RockWorks Utilities

Free trial available at www.rockware.com

$2,499



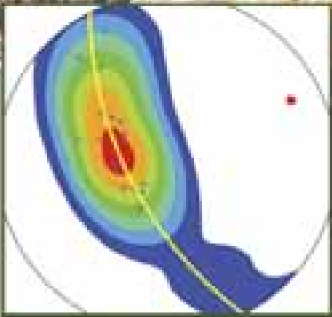
RockWorks Utilities™

An Indispensible Collection of Modeling, Analysis, and Display Tools

- Point maps
- Contour maps
- 3D surfaces
- Gridding tools
- Solid models
- Volumetrics
- Piper/Stiff plots
- Rose diagrams
- Stereonet diagrams

Free trial available at www.rockware.com

$599



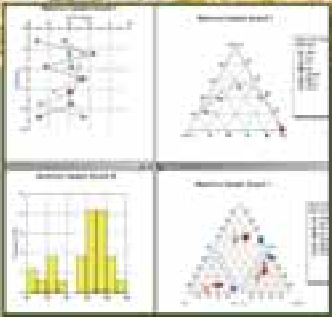
StereoStat™

Quickly Create Stereonets and Rose Diagrams, Perform Strain/Kinematic Analysis and Analyze Structural Databases

- Organize, manipulate, visualize and interpret datasets
- A must-have for anyone who needs high quality rose diagram, stereo and tangent plots

Free trial available at www.rockware.com

$299



AquaChem™

The Most Complete System for Water Quality Data Analysis, Plotting, Reporting and Modeling

- Features a fully customizable database of physical and chemical parameters and provides a comprehensive selection of analysis, calculation, modeling and graphing tools
- Plot types include correlation plots, summary plots, multi parameter plots, time-series plot, geothermometer & Giggenback plots, single sample plots, and thematic map plots

Free trial available at www.rockware.com

$1,390

ESRI Technology AUTHORIZED BUSINESS PARTNER

RockWare®
Since 1983

303.278.3534 · 800.775.6745 · RockWare.com

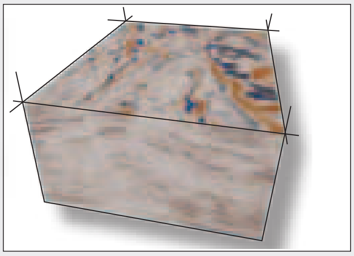
GSA TODAY

GSA TODAY publishes news and information for more than 22,000 GSA members and subscribing libraries. *GSA TODAY* (ISSN 1052-5173 USPS 0456-530) is published 11 times per year, monthly, with a combined April/May issue, by The Geological Society of America®, Inc., with offices at 3300 Penrose Place, Boulder, Colorado. Mailing address: P.O. Box 9140, Boulder, CO 80301-9140, USA. Periodicals postage paid at Boulder, Colorado, and at additional mailing offices. Postmaster: Send address changes to *GSA Today*, GSA Sales and Service, P.O. Box 9140, Boulder, CO 80301-9140, USA. GSA provides this and other forums for the presentation of diverse opinions and positions by scientists worldwide, regardless of their race, citizenship, gender, religion, or political viewpoint. Opinions presented in this publication do not reflect official positions of the Society.

SUBSCRIPTIONS: GSA members: Contact GSA Sales and Service at +1-888-443-4472, +1-303-357-1000, option 3, or gsaservice@geosociety.org for information. Nonmembers & Institutions: Free with paid subscription to *GSA Bulletin*, *Geology*, *Lithosphere,* and *Geosphere* (all four); otherwise US$70. Contact AIP Customer Service, subs@aip.org. Claims: For nonreceipt or for damaged copies, GSA members should contact GSA Sales and Service; all others contact AIP Customer Service, subs@aip.org. Claims are honored for one year; please allow sufficient delivery time for overseas copies, up to six months.

VOLUME 20, NUMBER 3 ▲ MARCH 2010

SCIENCE ARTICLE



Cover: Spectacular fold-thrust structure imaged by CGGVeritas from the deepwater Niger Delta—but is the deformation simply a matter of thrusting in unconsolidated sediments like this? Field of view ~5 km by 5 km × 3 seconds from a 3-D seismic cube image courtesy of the Virtual Seismic Atlas (www.seismicatlas.org). See "Evaluating lateral compaction in deepwater fold and thrust belts: How much are we missing from 'nature's sandbox"?, by R.W.H. Butler and D.A. Paton, p. 4–10.

Evaluating lateral compaction in deepwater fold and thrust belts: How much are we missing from "nature's sandbox"?

R.W.H. Butler, *Geology and Petroleum Geology, School of Geosciences, University of Aberdeen AB24 3UE, UK, rob.butler@abdn.ac.uk; and* ***D.A. Paton,*** *Institute of Geophysics and Tectonics, School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK, d.a.paton@leeds.ac.uk*

ABSTRACT

Deepwater fold and thrust belts offer unique opportunities for evaluating deformation in sedimentary successions with unrivalled seismic imaging of fold-thrust structures. A regional seismic line through the Orange Basin, offshore Namibia, reveals a classic paired, gravity-driven deformation system, over 100 km across, with extension high on the submarine slope and contraction toward the toe of slope. A mismatch between the minimum estimate of extension (44 km) and slip on thrusts (18–25 km) requires an additional longitudinal strain component of 18%–25% to be distributed across the system, most plausibly as lateral compaction and volume loss. Strains of this magnitude raise issues for understanding deformation in partially lithified strata, with implications for the applicability of theoretical fold-thrust models and the development of hydrocarbon resources in deepwater settings.

INTRODUCTION

The thick sedimentary sequences that characterize many of the world's continental margins hold an unstable secret of gravitational collapse, the scale of which has only become apparent through exploration for hydrocarbons in the past 20 years or so (e.g., Rowan et al., 2004). Although inaccessible, submerged beneath many kilometers of water, these structures are revolutionizing the understanding of the geometry of contractional deformation in sedimentary successions. They are *nature's sandbox*, large-scale versions of the laboratory physical models currently in vogue in some parts of the structural geology community (e.g., Adam et al., 2005). Here we examine one well-imaged system to learn more about the large-scale deformation of poorly lithified sedimentary rocks. Our case study comes from the continental margin of southwest Africa, offshore Namibia. By making independent estimates of the extension and the contraction, we show that there is a considerable amount of deformation that is not accounted for in the imaged thrust belt structures. We discuss how these inferred strains might be accommodated and outline the implications.

Deepwater fold and thrust belts are the down-slope expression of large-scale gravitational failure of submarine slopes (Rowan et al., 2004). They are paired with extensional structures higher on the slope (Fig. 1), with the two domains connected by a detachment preferentially located along a weak formation (salt, or, as in our study, over-pressured mudstone). There are two principal attractions for studying thrust systems created by gravity tectonics in deepwater systems. The first is that seismic reflection methods yield images of unrivalled clarity (Fig. 2). This means many of the ambiguities in structural interpretation are reduced, especially in defining stratal terminations against faults and thereby deducing the geometry and extent of thrust ramps and flats. Kinematic models that describe the relationship between folding, the geometry of stratal surfaces, and the displacement patterns on faults have been refined (e.g., Shaw et al., 2005) and reapplied (e.g., Briggs et al., 2006) in these settings. Second, purely gravity-driven systems are kinematically self-contained. The stratal shortening represented by the contractional structures, including the thrust and folds developed on the lower slopes, must balance the net extension accommodated higher on slopes. This attribute means estimates of the extensional motion can be used to constrain structural interpretations of the contractional domain. Our specific concern is whether the thrust and folds that can be interpreted from the seismic data are sufficient alone to balance the extension. If not, a further strain component is required, the value of which can be estimated. Distributed strains, long known as a component of foreland fold and thrust belts (e.g., Coward, 1988) and recently recognized in physical deformation models of granular

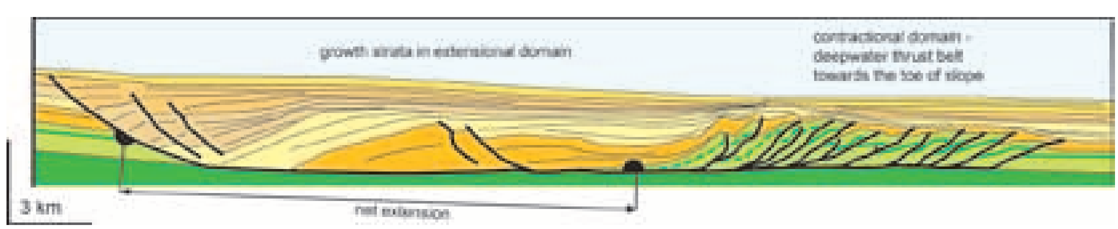


Figure 1. Architecture of gravity-driven thrust systems, based on the Pará-Maranhão basin, offshore Brazil (Zalan, 2005). The pre-kinematic section is shown in green and has been stacked up into a deepwater thrust belt on the lower slope. Sedimentation has continued (tan-yellow tones) and eventually buried the thrust belt. These syn-kinematic deposits are ponded in fault-related basins within the extensional domain, upslope from the thrust belt. The sediments show characteristic geometry of growth strata, thickening toward the main extensional faults and forming off-lapping depositional wedges that become progressively younger up the slope. Cumulative stratal shortening in the contractional domain should balance the net extension, here shown by the separation of pre-kinematic strata along the main detachment.

GSA Today, v. 20, no. 3, doi: 10.1130/GSATG77A.1

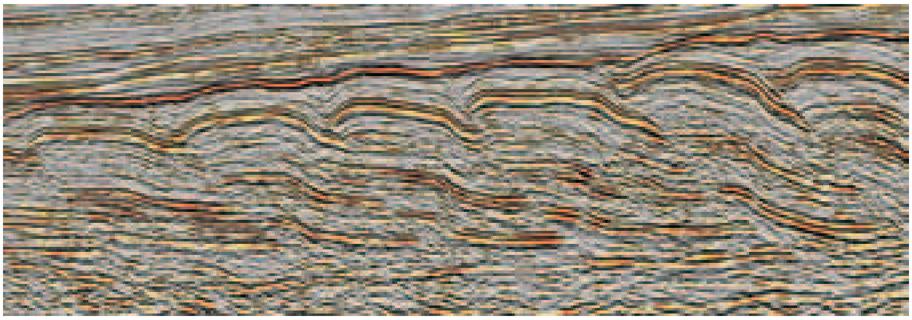


Figure 2. High-quality seismic reflection data reveal thrust and fold structural geometry offshore Namibia. The context is provided on Fig. 3; these are the lowest structures on the slope (thrusts 1–6 on Fig. 5A). This image is ~17 km across and 2.5 s (seismic two-way-time) high, which equates to an approximate vertical exaggeration of 5:1 assuming a constant seismic velocity of 2.7 km/s. Image courtesy CGGVeritas and the Virtual Seismic Atlas.

aggregates in the laboratory (e.g., Adam et al., 2005), are commonly ignored in seismic interpretation and are not generally considered in theoretical fold-thrust models (e.g., Shaw et al., 2005). Estimating the significance of distributed strains on a large scale, and how they might be accommodated, is important for the general understanding of deformation in sedimentary successions, especially those that are only partly lithified. Such deformation can also impact petrophysical properties, especially the performance of hydrocarbon reservoirs (e.g., Zahid and Uddin, 2005).

GEOLOGICAL SETTING AND REGIONAL STRUCTURE

The regional seismic line used in this study comes from the multi-client 2-D survey VERNOB03 acquired by CGGVeritas in 2003, offshore Namibia. The line is 215 km long and was originally recorded to 8 seconds. The acquisition streamer was 8 km long, with 320 receivers. The seismic profile was processed using modern Kirchhoff pre-stack migration that yields excellent reflector continuity, notwithstanding the structural complexity. The lack of image distortion and amplitude variations associated with structures indicates a simple seismic velocity structure that is a function of depth rather than stratigraphy. The profiles are shown here in seismic two-way-time. The measurements of bed-length and separations across faults are dominantly subhorizontal, so velocity variations are not considered to impact these significantly. Depth comparisons are provided in figure captions. The seismic line (Fig. 3) runs down in the dip direction of the continental margin and

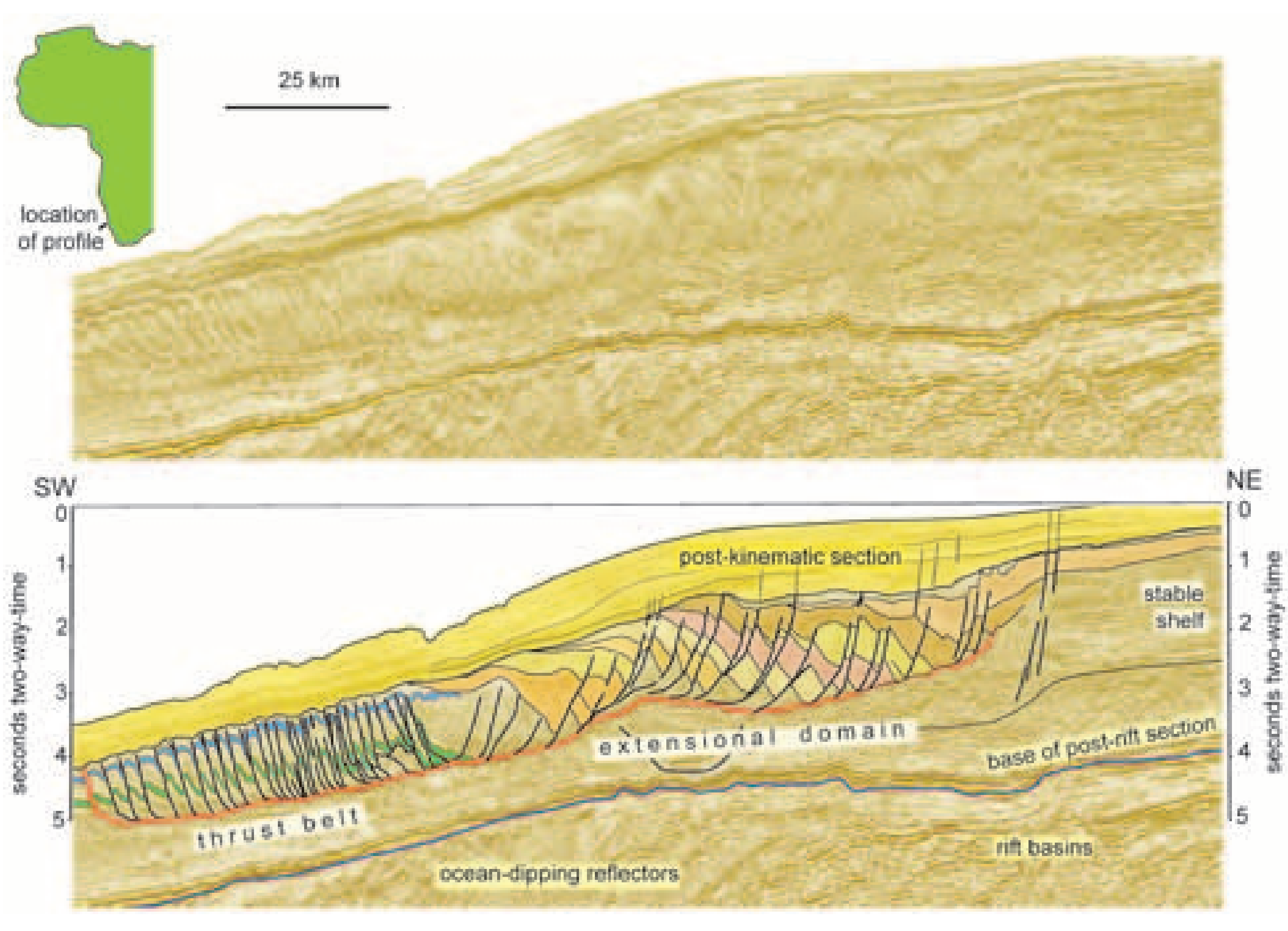


Figure 3. Regional seismic reflection profile across the continental margin offshore Namibia (see inset) shown in clean and interpreted form. Assuming a mean seismic velocity of 2.7 km/s, the vertical exaggeration is ~7:1. Original image courtesy of CGGVeritas and the Virtual Seismic Atlas.

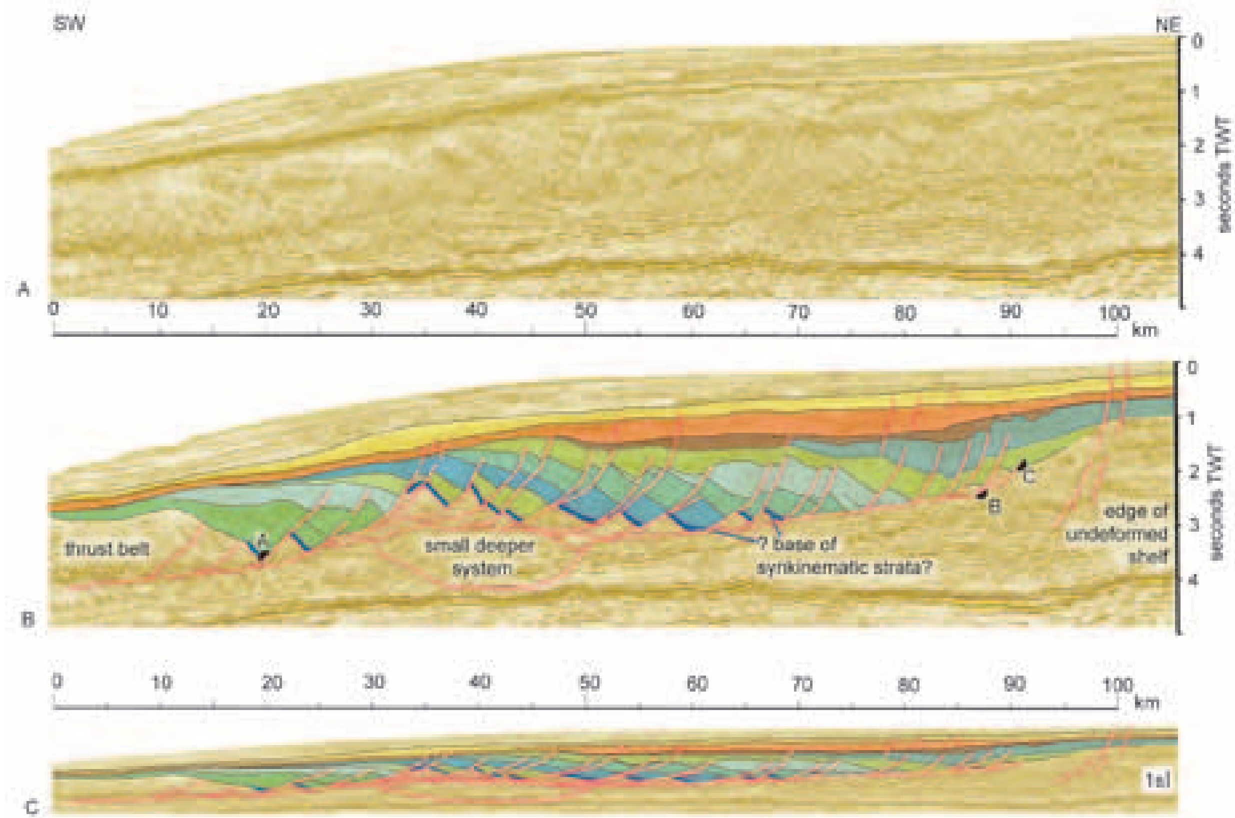


Figure 4. A structural interpretation of the extensional domain, offshore Namibia, as located on Fig. 3. A. Clean line (courtesy of CGGVeritas and the Virtual Seismic Atlas). B. Interpreted section showing arbitrarily selected correlations across faults and wedges of growth strata (green and blue tones). The base of the growth strata is outlined by the thick blue pick; regional detachment and faults are in red. These sections have a vertical exaggeration of ~ 3.75:1, assuming a constant velocity of 2.7 km/s. C. The same structure with little inferred vertical exaggeration. The maximum extension implied by the separation along the detachment (distance from A–C) is 71 km, reducing to 44 km if the residual pre-kinematic strata is included. See text for further discussion.

shows a prominent paired system of extension and contraction bounded top and bottom by undeformed strata. The images shown here are available via the Virtual Seismic Atlas (www.seismicatlas.org) so that readers can inspect the seismic line with and without interpretation.

The regional setting and tectonostratigraphic evolution of the margin, termed the Orange Basin, are described by Paton et al. (2008) and de Vera et al. (2009). Our study is concerned with deformation in part of the post-rift section. Although there is no well control on the line of section, the stratigraphy on the shelf can be tied regionally to wells on the shelf. Continental rifting in the Late Jurassic and Early Cretaceous led to continental breakup in the Barremian. Once established as a continental margin, a wedge of sediment built out (in places >5.5 km thick), sourced principally from the ancestral Orange River. Paton et al. (2008) note that this post-rift megasequence developed in two distinct phases, separated by a tilting episode that correlates with the deformation studied here. The regional detachment, together with the underlying strata, dips consistently toward the ocean. Thus, the deformation approximates to gravity sliding (Rowan et al., 2004).

STRUCTURAL INTERPRETATION

The general form of the gravitational deformation system is shown on Figure 3. The extensional domain is 80 km across, while the thrust belt is 55 km wide. The two domains are separated by a 10-km-wide zone where the seismic imaging and hence structural style is ambiguous. It is possible that this represents a transitional domain of polyphase deformation involving extension overprinting thrusting (de Vera et al., 2009), as found in other systems worldwide (e.g., Rowan et al., 2004). In the following discussion, the lack of clearly decipherable structures in this domain represents an interpretational uncertainty but this is considered here to be minor.

Beneath the main system interpreted on Figure 3 is a local patch of deformation, 20 km across. This is a small, paired extensional-contractional system, most likely formed toward the end of the translation on the main detachment above, which is broadly folded by it. The thrust ramp is essentially unmoved, with the anticline in its hanging wall remaining above the footwall ramp. Therefore, although the width of the structure and the structural relief created by it are significant, the amount of down-slope translation accommodated is likely to be rather small (<1 km). It is not considered further.

The structural geometry evident on the interpreted seismic section can be used to estimate the displacements, both in the extensional and in the contractional domain. As Bond et al. (2007) point out, geological interpretations are fundamentally non-unique. Therefore, we spend some time discussing interpretations and limitations. The two deformation domains (extensional and contractional) are considered independently, and the linear values for the two are compared to assess any shortfall in the required deformation. The analysis carries the tacit assumptions of plane strain and that there are no significant dips out of the plane, both of which are reasonable because the profile is perpendicular to regional slope.

The Extensional Domain

Figure 4 shows the extensional part of the system. Strata above the detachment are characterized by convex-upward geometries that diverge downward, increasing in dip as they do so, terminating against the system detachment. This pattern is diagnostic of growth strata in extensional systems (Williams, 1993; cf. Fig. 1). Up-dip, the growth strata are separated by normal faults (at B and C on Fig. 4B) from subhorizontal reflectors of the undeformed African shelf. Down-dip, the growth strata abut onto the transitional domain at the trailing edge of the thrust belt (A on Fig. 4B).

Evaluating the extent of growth strata in the extensional domain is important. If the entire stratal volume above the detachment is synkinematic, then the separation between the trailing edge of the thrust belt and the undeformed shelf, as shown on Figure 1, provides an estimate of the amount of extension. On Figure 4, this is the distance between points A and B, which is measured at 67 km. Note that if the trailing edge of the thrust belt (A) lies at the top of the stratal package, it would match with a higher position along the detachment (i.e., C on Fig. 4). Such an interpretation increases the total separation along the detachment to 71 km, a figure that can be considered to represent a maximum plausible estimate of the extension implied by this geological interpretation.

If 71 km represents the maximum value for extension, lower values are obtained if part of the rock volume in the hanging wall to the detachment is represented by pre- rather than wholly syn-kinematic strata. Such uncertainty exists within the geological interpretation because stratal geometries approaching the detachment are obscure. If these ambiguous portions are pre-kinematic, then the additional length of the top of these strata must be subtracted from the total separation value obtained. A conservative interpretation is shown on Fig. 4B, with the picked horizon at the top of possible pre-kinematic strata having an integrated restored length of 23 km. Thus, a conservative value for extensional movement on the detachment is 67 − 23 = 44 km.

Structure of the Thrust Belt

Section balancing has long been a mainstay of structural interpretation in thrust belts. Conventionally, when generating a structural interpretation, mismatches in bed-length are resolved to create a balanced cross section. The final version will be the result of considerable iteration and compromise, trading off lengths of beds, resolving thrust trajectories to create a coherent

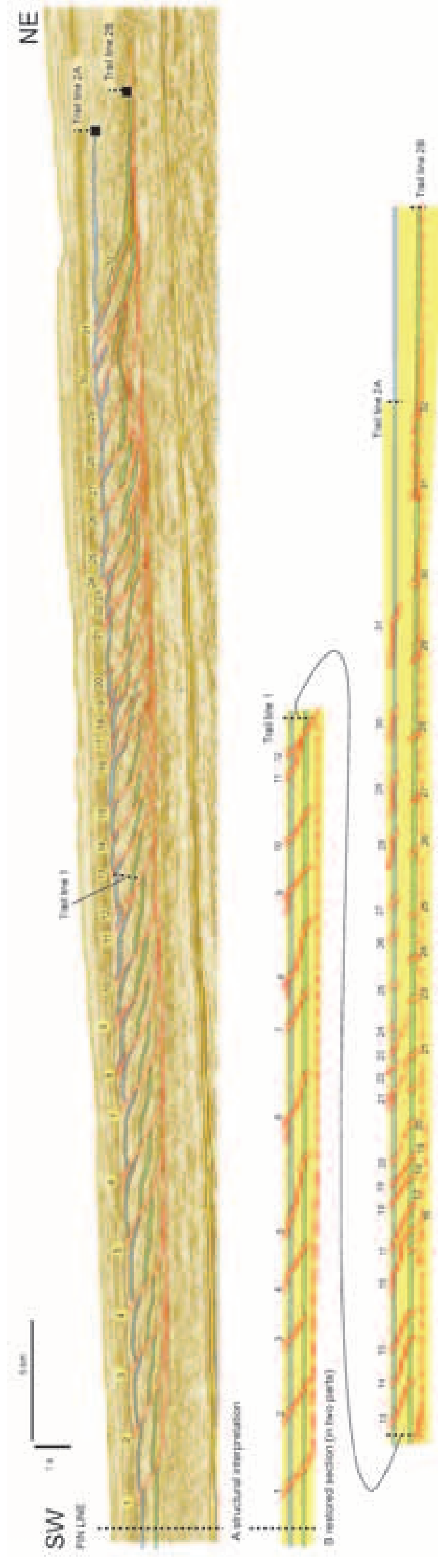


Figure 5. Structural interpretation of the thrust belt (A), offshore Namibia, and restoration (B) used to estimate the amount of stratal shortening represented in the contractional domain. The section is shown with no significant vertical exaggeration (assuming a seismic velocity of 2.7 km/s). Thrusts are numbered for reference and do not imply a sequence of formation. The deformed distance between the pin line and trail line 2A (blue horizon) is 58.5 km; its restored equivalent distance is 77 km, so the net contraction is 18.5 km. The deformed distance between the pin line and trail line 2B (green horizon) is 60 km; its restored equivalent is 85 km, so the net contraction is 25 km.

TABLE 1. CALCULATING STRAIN THROUGH THE GRAVITATIONAL TECTONIC SYSTEM USING MEASUREMENTS FROM FIGURE 5

Horizon	Present length	Restored length (thrusts only)	Shortening (thrusts only)	Missing length (km)	True restored length (km)	Missing strain
Blue	58.5 km	77 km	18.5 km	44 – 18.5 = 25.5	77 + 25.5 = 102.5	25.5/102.5 = 25%
Green	60 km	85 km	25 km	44 – 25 = 19	85 + 19 = 104	19/104 = 18%

geometric model of the present-day structure. The result may be used to estimate the large-scale shortening accommodated by the structures shown on the cross section, simply by subtracting the length of the final state section from that of its restored counterpart. An unusual strategy is adopted here, showing a cross section that does not balance in its entirety. By showing this "provisional" unbalanced cross section, we reveal interpretation uncertainties that would otherwise become iterated away, potentially implying unwarranted precision in the values for stratal contraction so obtained.

The thrust belt is here restored using two seismic-stratigraphic markers that can be correlated through the system and into the undeformed strata lying farther out on the abyssal plain. For the outer thrust system (thrusts 1–13, Fig. 5), the lengths of these two horizons restore to comparable lengths. The position of thrust ramps through the strata can be estimated with confidence given the clear imaging of matching hanging-wall and footwall stratal cut-offs. Deformation in these outer thrust slices appears therefore to be accommodated by thrust displacement and the associated folding of stratal layers. There is no difference between the restored lengths of the two marker horizons, indicating that there is no distributed strain accumulated heterogeneously in the section. Furthermore, the thickness of the two stratal layers and the intervening units is conserved from the undeformed section into and between the thrust slices. Thus, there is no evidence in these outer structures for distributed vertical stretching (layer parallel shortening). Consequently, the assumption of bed-length conservation inherent in the restoration appears valid.

In detail, the contractional structures upslope behind the lower thrust belt (14–29 on Fig. 5) become increasingly ambiguous. Although the two marker horizons can be traced confidently across the thrust belt, more problematic geometries arise from uncertainty in picking thrust cut-offs. Initially, this is manifest in a first-pass restoration as a cumulative mismatch on the restored section between the ramps cutting the two marker horizons (thrusts >23 on Fig. 5). The most upslope thrust slices (>29 on Fig. 5) are increasingly difficult to balance. Their seismic stratigraphy is harder to correlate across faults because the distinctiveness of the marker horizons is diminished. A number of different structural geometries satisfy the available data, and there may be further structures hindward of fault 32. The option chosen in Figure 5 is extreme, maximizing the amount of stratal length of the lower marker horizon. While creating a significant mismatch in the restored lengths of the two horizons, it inflates the required shortening value for the thrust belt as a whole. Comparing the shortening on the two marker beds therefore gives an estimate of uncertainty in the net contraction in the thrust belt. On Figure 5, the upper (blue) horizon shows 18.5 km shortening, while the lower (green) level shows 25 km. This difference might be explained by further shortening (concentrated in the blue marker horizon) in the poorly imaged zone of transition into the extensional domain, although this suggestion is speculative and unquantifiable.

Matching Displacements: Comparison between the Extensional and Contractional Domains

It is evident that the net contraction on folds and thrusts interpreted on Figure 5 (18.5 km–25 km) cannot accommodate the value required to balance even the minimum estimate of extension (44 km). We have not considered the structure of the poorly imaged transitional domain between the extensional and contractional structures, and therefore this represents an unquantified uncertainty in our analysis. However, if de Vera et al. (2009) are correct that extension and contraction are present in the transitional domain, the net effect is likely to be small. These authors also report a mismatch between extension and contraction on the whole section line. While their estimate of shortening in the thrust belt is broadly comparable with our minimum estimate (16 km vs. 18.5 km), we consider their value of extension (24 km) to be an underestimate caused by assuming excessive amounts of pre-kinematic strata within the extensional domain. The shortfall in required stratal shortening in both studies demands another strain component to be present and implies that our routine restoration of stratal lengths is insufficient.

VOLUME LOSS AND LATERAL COMPACTION

On occasion, the presence of distributed strain to achieve a balance in deformed multilayers (e.g., Butler, 1992) has been inferred and ductile layer parallel shortening measured (e.g., Coward, 1988) in some foreland fold and thrust belts. These examples have focused on well-lithified strata. However, where lithification is incomplete, contractional deformation can include volume loss. Henry et al. (2003) estimate 12% horizontal ductile shortening based on core samples from the Nankai

Figure 6. A conceptual model for gravitational tectonics on continental margins, where the down-dip translation associated with extension higher on the slope passes into a zone where contraction is accommodated by lateral compaction and volume loss. It is possible that in some situations the contractional deformation happens without any observable thrusting or folding.

subduction-accretion thrust system. Synkinematic fluid expulsion, and therefore volume loss, is evident in submarine thrust belts, especially where it is focused, for example, at mud volcanoes (e.g., Kopf et al., 2001). Recently, models of fold-thrust development have been modified to include strain and volume loss (e.g., Gonzalez-Mieres and Suppe, 2006). Our study of the Namibia deepwater fold and thrust belt offers an opportunity to quantify these effects on a regional scale.

If the stratal contraction in our Namibian study cannot be accounted for in full, the shortfall is presumably taken up as widely distributed ductile deformation (Fig. 6), as calculated in Table 1. This equates to 18%–25% longitudinal strain (or lateral volume loss) if distributed homogeneously through the entire contractional domain. This deformation presumably predated the localization of thrusts (Fig. 6), because thrust trajectories and bed dips, certainly for the well-imaged frontal part of the contractional domain (thrusts 1–12 on Fig. 5), appear unmodified by subsequent deformation. The seismic data show no evidence for minor faulting in picked horizons (e.g., Fig. 2) or for significant bed-thickness variations between the undeformed basin floor and thrust belt. Thus, the likely deformation mechanism accommodating this missing strain was distributed volume loss. Presumably, this strain was homogeneously developed with depth for the frontal thrusts (thrusts 1–12 balance the green and blue markers on Fig. 5). Heterogeneous lateral compaction (stronger in the blue horizon) may explain the mismatch between the restoration of markers toward the back of the contractional domain.

DISCUSSION

Our structural interpretation and restoration of the deepwater fold and thrust belt offshore Namibia indicates that a significant proportion of the slip required to balance the extensional displacements higher on the slope must be accommodated by widely distributed ductile deformation, most plausibly lateral compaction and volume loss (Fig. 6). The required values of 18%–25% volume loss are significant. We hope our investigation prompts further studies elsewhere to establish how deformation is partitioned between localized thrusting, ductile deformation, and lateral compaction, especially within poorly lithified sedimentary successions. Not only do these include other gravity-driven thrust belts but also accretionary prisms and parts of weakly buried foreland thrust belts. Our conclusions raise issues for structural analysis in these settings.

Lateral compaction renders the assumption of bed-length conservation, implicit in most theoretical descriptions of fold-thrust relationships (e.g., Shaw et al., 2005), invalid. A greater range of structural geometries exists with the additional freedom of significant distributed strain (e.g., Gonzalez-Mieres and Suppe, 2006). In hydrocarbon exploration, the application of the established fold-thrust models has led to over-optimistic predictions of structural integrity and, hence, oil column heights (e.g., Kostenko et al., 2008). Penetrative layer-parallel shortening and lateral compaction can lead to significant anisotropy in the poro-perm characteristics of reservoirs (e.g., Henry et al., 2003), which will have an impact during production. It is tempting to believe that when seismic imaging is as excellent as in deepwater thrust belts (e.g., Fig. 2) we can recognize all the deformation. Three-dimensional data can help to resolve smaller structures and distributed strains predicted here (e.g., Bangs and Gulick, 2005), perhaps using regional maps of seismic amplitude anomalies. The challenge lies in placing these detailed studies in their regional context so models of the kinematic evolution of the contractional domains can be tested against the deformation requirements of the whole gravitational system.

ACKNOWLEDGMENTS

The images used for this paper were released to the Virtual Seismic Atlas (VSA) by CGGVeritas (formerly Veritas DGC), which is gratefully acknowledged. All images used here are available for inspection and re-interpretation on the VSA at www.seismicatlas.org. In addition, we thank R. Morgan and W.D. McCaffrey for discussions on deepwater systems, together with two anonymous referees and editor Stephen Johnston for helpful comments on an earlier draft. Our work on submarine thrust belts was supported by BHP-Billiton.

REFERENCES CITED

Adam, J., Urai, J.L., Wieneke, B., Oncken, O., Pfeiffer, K., Kukowski, N., Lohrman, J., Hoth, S., van der Zee, W., and Schmatz, J., 2005, Shear localization and strain distribution during tectonic faulting—New insights from granular-flow experiments and high-resolution optical image correlation techniques: Journal of Structural Geology, v. 27, p. 283–301.

Bangs, N.L.B., and Gulick, S.P.S., 2005, Physical properties along the developing décollement in the Nankai Trough: Inferences from 3-D seismic reflection data inversion and Leg 190 and 196 drilling data, *in* Mikada, H., Morre, G.F., Taira, A., Becker, K., Moore, J.C., and Laus, A., eds, Proceedings of Ocean Drilling Program Legs 190/196, Scientific Results, p. 1–18.

Bond, C.E., Gibbs, A.D., Shipton, Z.K., and Jones, S., 2007, What do you think this is? "Conceptual uncertainty" in geoscience interpretation: GSA Today, v. 17, no. 11, p. 4–10.

Briggs, S., Davies, R.J., Cartwright, J.A., and Morgan, R., 2006, Multiple detachment levels and their control on fold styles in the compressional domain of the deepwater west Niger Delta: Basin Research, v. 18, p. 435–450.

Butler, R.W.H., 1992, Structural evolution of the western Chartreuse fold-thrust system, NW French Subalpine chains, *in* McClay, K.R., ed., Thrust Tectonics: London, Chapman & Hall, p. 287–298.

Coward, M.P., 1988, The Moine thrust and the Scottish Caledonides, *in* Mitra, G., and Wojtal, S., eds, Geometries and mechanisms of thrusting with special reference to the Appalachians: GSA Special Paper 222, p. 1–16.

de Vera, J., Granado, P., and McClay, K.R., 2009, Structural evolution of the Orange Basin gravity-driven system, offshore Namibia: Marine and Petroleum Geology, v. 27, p. 223–237.

Gonzalez-Mieres, R., and Suppe, J., 2006, Relief and shortening in detachment folds: Journal of Structural Geology, v. 28, p. 1785–1807.

Henry, P., Jouniaux, L., Screaton, E.J., Hunze, S., and Saffer, D.M., 2003, Anisotropy of electrical conductivity record of initial strain at the toe of the Nankai accretionary prism: Journal of Geophysical Research, v. 108, doi: 10.1029/2002JB002287.

Kopf, A., Klaeschen, D., and Mascle, J., 2001, Extreme efficiency of mud volcanism in dewatering accretionary prisms: Earth and Planetary Science Letters, v. 189, p. 295–313.

Kostenko, O.V., Naruk, S.J., Hack, W., Poupon, M., Meyer, H-J., Mora-Glukstad, M., Anowai, C., and Mordi, M., 2008, Structural evaluation of column-height controls at a toe-thrust discovery, deep-water Niger Delta: AAPG Bulletin, v. 92, p. 1615–1638.

Paton, D.A., van der Spuy, D., di Primio, R., and Horsfield, B., 2008, Tectonically induced adjustment of passive-margin accommodation space; influence on hydrocarbon potential of the Orange Basin, South Africa: AAPG Bulletin, v. 92, p. 589–609.

Rowan, M.G., Peel, F.J., and Vendeville, B.C., 2004, Gravity-driven fold belts on passive margins, *in* McClay, K.R., ed., Thrust tectonics and hydrocarbon systems: AAPG Memoir 82, p. 157–182.
Shaw, J.H., Connors, C., and Suppe, J., eds., 2005, Seismic interpretation of contractional fault-related folds: An AAPG Seismic Atlas: AAPG Studies in Geology 53, p. 156.
Virtual Seismic Atlas, 2008: SeismicAtlas.org, University of Aberdeen and University of Leeds, http://www.seismicatlas.org (last accessed 11 Jan. 2010).
Williams, G.D., 1993, Tectonics and seismic sequence stratigraphy: An introduction, *in* Williams, G.D., and Dobb, A., eds., Tectonics and seismic sequence stratigraphy: London, Geological Society Special Publication 71, p. 1–14.
Zahid, K.M., and Uddin, A., 2005, Influence of overpressure on formation velocity evaluation of Neogene strata from the eastern Bengal Basin, Bangladesh: Journal of Asian Earth Sciences, v. 25, p. 419–429.
Zalan, P.V., 2005, End members of gravitational fold and thrust belts (GFTBs) in the deep waters of Brazil, *in* Shaw, J.H., Connors, C., and Suppe, J., eds., An AAPG Seismic Atlas: AAPG Studies in Geology 53, p. 147–156.

Manuscript received 17 Aug. 2009; accepted 23 Sept. 2009. ✺

LETTER

Dear Editor,

I refer to the "Final Report" of the Congressional Science Fellow in the December *GSA Today**. Mr. Szymanski's report clearly shows his bias with respect to the proposition that mankind is responsible for global warming. I also noted that the GSA is in the process of reframing its official position on global warming and its causes, a position heretofore firmly biased in the same direction as that of the Congressional Science Fellow.

I am a lifetime geoscientist whose geological training and experience have led me to examine all scientific findings with a degree of skepticism. The Saint Gore school of global warming extremists, never willing to be debated by competent scientists with a differing perception, have run aground in the light of disclosures of rigged scientific data sets. This disclosure does not really surprise me, especially when a reasonable examination of the available data (in unblemished form) requires a scientific mind to seek and test alternative explanations for global warming other than mankind's CO_2 contribution to the atmosphere.

The real shock of this exposure is the revelation of intentional data rigging by alleged professional climatologists—and among them, their geologist fellows. Have we, in our search for the truth, become so susceptible to political pressures—and financial rewards—that we are quite willing to engage in the prostitution of our science? What becomes of our profession if we fail to cleanse our ranks of those who freely engage in intentional falsification of data and their interpretation? I, for one, desire to be disassociated with such charlatans and to be counted by my fellow Americans as a searcher for the truth who can be counted on to cling to our professional standards.

Yours very truly,

Richard P. Palmer, *a 50-year GSA member*

---

*v. 19, no. 12, p. 20–21

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. *GSA Today* reserves the right to edit letters for space and clarity, and opinions presented do not reflect official positions of the Society. Find more letters at **www.geosociety.org/gsatoday/letters/.**

THE GEOLOGICAL SOCIETY OF AMERICA®

GSA ELECTIONS

GSA's success depends on its members and the work of the officers serving on GSA's Executive Committee and Council. In late February, you will receive a postcard with instructions for accessing your electronic ballot via our secure Web site, and biographical information on the nominees will be online for you to review at that time. Paper versions of both the ballot and candidate information will also be available. Please help continue to shape GSA's future by voting on the nominees listed here.

2010 Officer and Council Nominees

PRESIDENT
(July 2010–June 2011)
Joaquin Ruiz
University of Arizona
Tucson, Arizona, USA

VICE PRESIDENT
(July 2010–June 2011)
John W. Geissman
University of New Mexico
Albuquerque, New Mexico, USA

TREASURER
(July 2010–June 2011)
Jonathan G. Price
Nevada Bureau of Mines & Geology
Reno, Nevada, USA

COUNCILOR POSITION 1
(July 2010–June 2014)
Bruce R. Clark
The Leighton Group Inc.
Irvine, California, USA
Scott Tinker
University of Texas
Austin, Texas, USA

COUNCILOR POSITION 2
(July 2010–June 2014)
Barbara L. Dutrow
Louisiana State University
Baton Rouge, Louisiana, USA
Martin B. Goldhaber
U.S. Geological Survey
Denver, Colorado, USA

COUNCILOR POSITION 3
(July 2010–June 2014)
Daniel Larsen
University of Memphis
Memphis, Tennessee, USA
Allen J. Dennis
University of South Carolina
Aiken, South Carolina, USA

Ballots accepted beginning 25 February 2010

Ballots due electronically or postmarked by 26 March 2010

Tectonic Development of the Amerasia Basin

Banff Centre, Alberta, Canada

4–9 October 2009

CONVENERS

Lawrence Lawver, University of Texas at Austin, Institute for Geophysics, 10100 Burnet Road, R2200, Austin, TX 78758-4445, lawver@utig.ig.utexas.edu
Victoria Pease, PetroTectonics Centre, Dept. of Geology & Geochemistry, Stockholm University, SE-106 91 Stockholm, Sweden, vicky.pease@geo.su.se
Ruth Jackson, Natural Resources Canada, 1 Challenger Drive, Room H-507 Dartmouth, Nova Scotia B2Y 4A2, Canada, rujackso@nrcan-rncan.gc.ca

DESCRIPTION

A sequel to the 1995 Penrose meeting, "The Tectonic Development of the Canada Basin and Surrounding Basins," also held in Banff, this conference turned out to be much more than a simple update. In October 2009, 59 scientists from the U.S., Canada, Russia, England, Sweden, Norway, Australia, Germany, and Denmark came together to present new data and new ideas concerning the tectonic development of the Amerasia Basin. Fifteen participants attended the original 1995 meeting, including three of the conveners, and nine of the attendees were graduate students. As with the 1995 meeting, generous sponsorship was much appreciated from industry; 2009 contributors included BHP, BP, ConocoPhillips, ExxonMobil, Shell, and ION GX Technology. Because of this support, registration fees for graduate students were waived and were substantially reduced for all other participants.

The amount of new data from the Amerasia Basin is staggering, yet there is still no clear-cut answer to how or when the Amerasia Basin developed. Looming United Nations Convention on Law of the Sea [UNCLOS] claims for additional Arctic territory have spurred a substantial amount of new and ongoing research, including the spectacular new multibeam data presented by Larry Mayer and brand-new seismic reflection data presented by Ruth Jackson, Debbie Hutchinson, and others.

Different aspects of the Amerasia Basin were emphasized each day—Monday: ridges and highs; Tuesday: the continental margins; Thursday: shelves and basins; and Friday: resource perspectives, including some extremely interesting but differing views from industry participants. A one-day field trip on Wednesday, exploring the folding and thrusting of the Canadian Rockies, was ably led by Clint Tippett of Shell Canada Ltd.

Highlights

- New multibeam bathymetry from around the Chukchi Borderland and along the eastern side of the Mendeleev Ridge;
- Long seismic reflection lines collected by joint Geological Survey of Canada and *USCGC Healy* surveys;
- Intra-plate lavas recently dredged from the Chukchi Borderland region;
- Spectacular deep seismic reflection lines collected on the shelves, particularly the lines in the Mackenzie Delta region shown by Menno Dinkelman of ION GX Technology;
- Seismic reflection and refraction data bearing on the crustal structure of the junction between the Lomonosov Ridge and Ellesmere Island collected by a joint Canadian-Danish operation;
- Multichannel seismic reflection and sonobuoy seismic refraction results from the Amerasia Basin collected by a joint U.S.-Norwegian operation in 2005;
- Sea-ice seismometer data from Chukchi Cap and the Mendeleev Ridge collected in 2006;
- Seismic reflection and refraction data from the Mendeleev Ridge that suggests it is contemporaneous with the oceanic crust on which it sits and therefore oceanic in nature;
- The Cretaceous age of the Makarov-Podvodnikov Basin between the Mendeleev and Lomonosov Ridges;
- Mapping and structural analysis constraining field relationships;
- Heavy mineral and detrital zircon data constraining sediment depocenters and pathways;
- Floral, faunal, and paleomagnetic constraints on Arctic paleogeography;
- Terrane correlations;
- Aerogeophysical data from the Canada Basin; and
- New and improved tectonic reconstructions.

The resource perspectives session included Steve Bergman of Shell, who reprised his presentation from 1995 with new insights into the evolution of the region. It was very clear that his ideas had changed substantially. He was followed by quite different interpretations of the tectonics and the evolution of the Arctic by Steve Matthews of BP, Steve Creaney of ExxonMobil, and Jim Dietrich of the Geological Survey of Canada. The meeting ended with an update from Bernie Coakley on future Arctic drilling targets and possibilities. He made the point that many of the unanswered questions about the tectonic evolution of the Amerasia Basin will only be decided with targeted drilling.

SUMMARY

In the early 1990s, there were a number of differing models concerning the tectonic evolution of the Arctic. The intervening years have actually resulted in *less* agreement as to the nature and age of the Arctic Ocean crust. The Chukchi Borderland and the major trans-basin ridges, the Alpha and Mendeleev ridges, present obstacles to a simple rotational opening of the Canada Basin as originally proposed by Warren Hamilton and

Irv Tailleur. It is generally agreed, and new seismic refraction and gravity data confirm, that at least parts of the Chukchi Borderland are continental, but there is still major disagreement concerning the nature of the Alpha and Mendeleev ridges. Previously, there was not much question concerning the oceanic nature of the deeper parts of the Amerasia Basin even if there had been little agreement concerning the age of the seafloor. Now, there are several theories regarding the nature of the deeper seafloor, ranging from oceanic, to transitional, to continental for more than just the shallower parts of the Alpha and Mendeleev ridges. The gravity signature of a probable abandoned spreading center in the Canada Basin trending toward the Mackenzie Delta region is asymmetric, based on new seismic profiles, with greater depth-to-basement toward the Canadian margin. The regional distribution of these new profiles, combined with over 90% of 82 sonobuoys recording converted crustal shear waves, will produce a regional distribution of the continental, transitional, and oceanic crustal affinities, and these new data will undoubtedly provide constraints for the various plate tectonic scenarios.

Even though a great deal of fundamental work has been accomplished since 1995, it has not provided the expected easy answers. The 2009 Penrose Conference focused thoughts on tectonic models and exposed some areas of basic knowledge that need work. Offshore, this includes the nature of the plate boundary between the Lomonosov Ridge continental fragment and the Amerasia Basin, the nature of the other basin margins (is the North Greenland margin strike-slip?), the age of the oldest sediment in the Canada Basin, ages and sources of intrusives both in the basin itself and along its margins, and the true nature of the Alpha and Mendeleev ridges, a subject still controversial after all these years and now even more important given pending UNCLOS claims. There was universal agreement that more data of all types are needed, including seismic and denser coverage of the aeromagnetic data. Onshore, circum-Arctic margins require more detailed mapping and sampling. These vast, remote, and consequently poorly studied regions often provide real “value for money” since the field investigations needed to understand age-relationships, to identify piercing points and sutures, to link on-shore with off-shore geology, etc., are often less costly than their marine counterparts.

The conference also provided a forum to develop new ideas and to coordinate future work and joint investigations. New investigations are planned for the Brooks Range and Yukon regions, Ellesmere Island, northeast Greenland and Baffin Bay in North America, and for Taimyr and Chukotka in the Russian Arctic. A clear need was expressed for more data from the Arctic Islands (e.g., Wrangel, New Siberian, and DeLong Islands). Seismic data over the shelf regions are necessary to connect on-shore with shelf and island geology, and to link this to the deep basin—critical to unraveling the mysteries of the Amerasia Basin. New initiatives, such as the Circum-Arctic Lithosphere Evolution (CALE) project being coordinated by V. Pease, will specifically address this topic over the coming five-year period. It was also clear that many of the unanswered questions about the tectonic evolution of the Amerasia Basin will only be decided with targeted sampling cruises—the need for sample material means that future Arctic drilling initiatives are a definite priority.

Although we may be close to a breakthrough in understanding the tectonic development of the Amerasia Basin with the integration of geological, geophysical, and geochronological observations combined with modeling and interpretation, we are not there yet. Mikhail Kos’ko does not think he can wait another 14 years for the next meeting and hopes that we can reconvene in perhaps eight years from now. As we know, the Amerasia Basin and the surrounding region will not give up their secrets easily.

Participants: Front row: Nina Ivanova, Galina Ledneva, Lawrence Lawver, Elizabeth Miller, Victoria Pease, Sergey Sokolov, Jane Gilloti, Marianna Tuchkova, Julie Dumoulin. Second row: Deping Chian, Clint Tippett, Ruth Jackson, Dwight Bradley, Kelly Brumley, Sam Mukasa, Shawn Malone, Marwin Wartes, Grace Shephard, Michelle Ickrath, Dietmar Müller. Third row: Elena Miloradovskaya, Lindsay Lowe Worthington, Steve Rippington, Helen Smythe, Sergey Drachev, Nick Kuzmir, Richard Whittaker, Jim Dietrich, Vladimyr Verbitzsky, Anne Hegewald. Fourth row: Wilfried Jokat, Bill McClelland, Tom Moore, David Stone, Bernie Coakley, Matt Malkowski, Larry Mayer, Meredith Petrie, Maurice Colpron, Rick Saltus, Ian Norton. Back: Karsten Pipejohn, Robert Scott, Harm van Avendonk, Steve Bergman, Thomas Funck, Richard Tozer. Not shown: James Buchanan, Steve Creaney, Menno Dinkelman, Art Grantz, Debbie Hutchinson, Derik Kleibacker, Mikhail Kos’ko, Yngve Kristoffersen, Larry Lane, Steve Matthews, Niall McAllister, Gil Mull, and Jaime Toro. Photo by Gil Mull.

DRAFT

Panel Seeks Input on GSA Position Statement Draft

Diversity of the Geoscience Community

GSA members are invited to submit comments and suggestions regarding the following *Position Statement draft* by **22 March 2010** at **www.geosociety.org/geopolicy/.** Go to **www.geosociety.org/positions/** to learn more.

POSITION STATEMENT

The Geological Society of America (GSA) affirms the value of diverse ideas and the connection between diverse ideas and the diverse group of contributors of those ideas, including those who comment and criticize.

PURPOSE

This position statement (1) summarizes the consensus views of GSA regarding the importance and value of diversity; (2) provides information that is intended to raise awareness among geoscience professionals implementing those policies and evaluating the short- and long-term consequences; and (3) encourages geoscientists to participate in implementing suitable diversity practices at local, regional, state, and national levels.

RATIONALE

Diversity, in today's lexicon, generally refers to variety in race or ethnicity, gender, religion, age, sexual orientation, marital status, national origin or ancestry, education, class, and physical and mental abilities. The concept of diversity is complex and has both positive and negative connotations. On the positive side, the variations found among humans collectively speak to a richness of resources, perspectives, and experience. A diverse Society membership (or workforce) is usually more capable, insightful, responsive, and dynamic than one that offers very little contrast. On the negative side, some see unfamiliar characteristics as unsettling, threatening, objectionable, distasteful, unpleasant, or offensive. Such reactions often lead to judgments based on perceived identity rather than on the merits of the individual. These can, ultimately, lead to exclusion.

It is critical that GSA enhance its diversity—philosophically and operationally—thereby maximizing the benefit to both its individual members and to the organization. This will optimize GSA's ability to serve society as a whole. GSA must vigorously and proactively reject prejudice and stereotyping wherever it is encountered in our profession, while actively promoting a diverse workforce.

During these times, our science must be justified and relevant to achieve a positive standing in performance and value to the community. There is increased scrutiny of scientists and scientific organizations regarding societally relevant issues and how they are addressed. Cultural variety supports diverse points of view and diverse positions on issues. Awareness of and respect for these issues—related to geoscience or not—is important in achieving solutions to problems that work well for all of those affected. Through integration of individual perspectives and diverse backgrounds and cultures, coupled with critical thinking, analysis, and problem solving, issues can be identified and a full range of possible solutions can be considered.

The GSA community is dedicated to maintaining an organizational climate where diverse ideas are welcomed. GSA intends to foster an open forum for discussion and exploration by geoscience professionals of varied personal backgrounds—reflecting differences in culture and origin and rejecting prejudice and stereotyping. Diverse perspectives are important and necessary for responsible, effective decision making and leadership. Other benefits of a diverse profession include increased options in attracting the best and brightest minds into the field and communicating with and educating the public ("Earth literacy").

PUBLIC POLICY ASPECTS OF DIVERSITY AND DERIVED BENEFITS

Mutual respect is key to successful diversity policy. The GSA community is dedicated to enacting codes of conduct that include demonstrating professionalism toward all colleagues. Within a diversity effort, groups might "allow" participation but still ignore certain members (or worse, be disrespectful to them directly or about them to others). Respect (treating others with courtesy and dignity; self awareness; sensitivity to the interpretation and potential impact of communications and actions; and appreciation and valuing of differences) is needed before participation and progress toward true inclusion can occur.

One key benefit of diversity is the opportunity posed by a rich cultural mixture, along with the idea that there is no single "right way" to do things. Openness to wide-ranging ideas and pathways to progress is the life-blood of science. Who can know the origin of an idea? What nuances of a person's upbringing, cultural milieu, education, social interactions, and ethnicity may lead to an advancement of human knowledge?

It is important to remember that the geosciences have a significant service function; GSA's ability to serve will be enhanced through the active, engaged participation of a diverse membership. A diverse membership will also create an environment that encourages new members to join the Society, enhancing GSA's growth and potential for advancement.

Another benefit of a diverse workforce is the achievement of more complete societal support for the earth sciences. As more groups become more engaged in the earth sciences, and as their knowledge and appreciation increases, there is a likelihood that the earth sciences will be more strongly supported and that citizens will make better choices regarding Earth issues.

RECOMMENDATIONS

This GSA Position Statement on diversity addresses both GSA staff and membership; headquarters activities, meetings, and special functions; and the role of GSA and its members in their larger communities. In this latter regard, the statement challenges the membership and all GSA units to deal with the complexity of issues related to diversity in their home institutions, whether they are academic, governmental, non-profit, or industry.

GSA is committed to making Earth literacy available to all and to having geoscience professionals, including its membership, reflect population diversity, and will undertake reasonable efforts to ensure that its activities are open to all. Although it is noted that a diverse climate cannot be achieved through rules, it *can* be encouraged and nurtured through processes that educate leaders and participants on the benefits of and pathways to equity and balance.

Implementation of the following recommendations is a major element in achieving the goals of this Position Statement. It includes elements that GSA, as an organization, and particularly its leadership (Council and the Executive Director), need to address, and elements that individual members (in their GSA-related activities and otherwise) are herein challenged to employ. *Those elements include*

- **Current Status**—There is a lack of quantitative and qualitative understanding of the current status of diversity-related issues and conditions in, and associated with, GSA. This needs to be addressed by GSA in a structured, timely, and ongoing manner.
- **Corrective Actions**—GSA must commit to addressing organizational gaps or deficiencies identified in the status analysis. This includes encouraging specific actions by individual GSA members or GSA as an organization.
- **Assessment**—This Position Statement defines the "yardstick" that may be used to measure progress as GSA and its members begin the implementation process. What benchmark should be used to measure diversity in GSA? Commonly used demographic parameters are a starting point, but this effort calls for broader sociological and ethical metrics that align with the objectives posed, along with utilizing the specialized expertise needed to make the assessment.
- **Dissemination**—Implementation includes GSA's commitment to establishing and engaging a plan for disseminating its position on diversity throughout the membership and promoting both increased communication and increased advocacy to support the actions of members toward achieving the goals posed by this Position Statement.

OPPORTUNITIES FOR GSA AND ITS MEMBERS TO HELP IMPLEMENT RECOMMENDATIONS

To facilitate implementation of the goals of this Position Statement, GSA recommends the following actions to increase the involvement of geoscientists in local, regional, statewide, and federal diversity policy decisions:

- *Seek opportunities to communicate effectively the value of a diverse workforce and of implementing suitable diversity practices to all levels of government, to private industry, and to academia.* GSA members are encouraged to work with print, electronic, and broadcast media in promoting the value of rational approaches for addressing critical diversity issues. Members who engage with diversity issues are encouraged to share their experiences at GSA meetings. If possible, it is beneficial to provide local examples of where efforts to promote a diverse workforce or implement diversity practices have been successful.
- *Seek opportunities to communicate effectively the value of a diverse workforce and of implementing suitable diversity practices with community groups.* The public must be able to respond in an informed manner to diversity decision making that potentially can have detrimental effects; thus, there is a growing need for the public to be educated about the value of diversity.
- *Participate in professional forums and town hall meetings for open community discussions on the importance of a diverse workforce and implementing suitable diversity practices.* Discussions should emphasize the value of rational information for diversity and its sustainability outcomes.
- *GSA should provide readily accessible print, Web, and personnel resources to members that support geoscientists' communications with decision makers regarding the value of a diverse workforce and implementing suitable diversity practices.* Considerable expertise and resources are available to members through GSA's Geology and Public Policy Committee and GSA's Geology and Society Division. GSA expertise can help members participate in policy decisions regarding diversity by creating talking points on common diversity problems and providing examples of how they can participate in diversity decisions by becoming members of relevant decision-making bodies. It is important that GSA and its members identify legislation that affects diversity and alert the Geology and Public Policy Committee, Geology and Society Division, and GSA's Associated Societies if action by the GSA membership and affiliated organizations can help improve the rational basis for diversity decisions. The Geology and Public Policy Committee, Geology and Society Division, and Director for Geoscience Policy, often working with GSA members, can also bring this Position Statement to the attention of lawmakers when legislation affects diversity.
- *GSA can raise awareness of diversity issues by publishing articles on the links between diversity and geoscience policy, planning, and management decisions.*

THE GEOLOGICAL SOCIETY OF AMERICA®

SCIENCE • STEWARDSHIP • SERVICE

Coming to *GSA Today* in April/May 2010

- **Science Article:** The Digital Revolution in Geologic Mapping by Whitmeyer et al.
- **First Announcement and Call for Papers:** 2010 GSA Annual Meeting & Exposition, “Reaching New Peaks in Geoscience”

GSA Today articles from 1995 on are open access via link at **www.geosociety.org/pubs/.**

2010 GSA Section Meetings

Northeastern–Southeastern Joint Meeting
13–16 March, Baltimore, Maryland, USA
Exploring the Connections between Continent and Sea

North-Central–South-Central Joint Meeting
11–13 April, Branson, Missouri, USA
Join Us for Springtime in the Ozarks

Rocky Mountain Section Meeting
21–23 April, Rapid City, South Dakota, USA
Early registration deadline: 22 March 2010

Cordilleran Section Joint Meeting with Pacific Section, AAPG
27–29 May, Anaheim, California, USA
Early registration deadline: 26 April 2010

GSA Section Meeting Mentor Program Schedule

ROY J. SHLEMON MENTOR PROGRAM IN APPLIED GEOSCIENCE LUNCHEONS

Northeastern/Southeastern: Sun., 14 March, and Mon., 15 March

North-Central/South-Central: Mon., 12 April, and Tues., 13 April

Rocky Mountain: Wed., 21 April

Cordilleran: Thurs., 27 May (two luncheons this day)

JOHN MANN MENTORS IN APPLIED HYDROGEOLOGY LUNCHEONS

Northeastern/Southeastern: Tues., 16 March

North-Central/South-Central: Mon., 12 April

Rocky Mountain: Fri., 23 April

Cordilleran: Sat., 29 May




Photos from left to right: Baltimore at night. Photo courtesy Visit Baltimore. Worm burrows. Photo by Kevin R. Evans. Mount Rushmore, South Dakota, USA. Photo by South Dakota Tourism. Orange County coastal sunset, courtesy http://static.panoramio.com/photos/original/3679706.jpg.

Donna L. Russell, *Director of Operations*

Funding for GSA's Research Grants Program

GEOSTAR
Supporting The Advancement of Research

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 and 9,186 grants later, GSA's Research Grants Program is still growing and providing young scientists with much-needed funding.

The origins of many important discoveries and advances in earth science may be traced to GSA grants, and these grants have often supported the early work of now-prominent earth scientists—men and women who have moved the science into new dimensions or found the answers to questions that persistently puzzled a generation of workers. At the start of their careers, many Penrose (the award that has been called *the Nobel Prize of geology*) and Day medalists received GSA research grants, and before they became Society presidents, several of GSA's leaders received financial support from GSA's Research Grants Program.

GSA gained the funds to support research beginning in 1931 with the receipt of a bequest of US$3,900,000 from R.A.F. Penrose, an endowment that has financed Society activity in research and publications ever since. However, the demand for research money is expanding, while customary sources, such as government and industry, are being restricted. While the Society has been able to fund a larger portion of the requests for research assistance each year, the available dollars are not enough to cover them all. GSA's ability to provide this funding must increase if we are to continue to have a strong flow of young talent and bright ideas into the earth sciences and thus uphold our mission to support the profession.

What geoscientists have told us about their GSA grants:

"The monetary award was greatly appreciated and only outweighed by the distinction in receiving a research grant from such a respected scientific organization."

"I would like to express what an honor this grant is to me because of the great respect I have for GSA projects as other funding remains tight."

"This funding has been invaluable to the success of my research."

"I will never forget the support that GSA once gave me, helping a foreign student to finish an M.S. thesis."

GEOSTAR augments GSA's Research Grants Program. This fund was created in 1987 with a US$10,000 gift from Leighton & Associates, a California engineering geology consulting firm. Currently, the net assets of **GEOSTAR** are about US$250,000; however, the Foundation needs to increase the balance substantially in order to provide funding for research grants.

Contributions to **GEOSTAR** from individuals, industry, and institutions are vital—please be generous with your support and help a young geoscientist! Send a check to the GSA Foundation, 3300 Penrose Place, Boulder, CO 80301, USA, using the coupon below; donate online at gsafweb.org; or call +1-303-357-1054 to make a donation over the phone.

GSA Section Meetings

Stop by the Foundation Booth at GSA's Section Meetings this spring. Among other items of interest, we will have information available on GSA student opportunities.

Support GSA Programs

Donate now!

1. **Enclosed is my contribution in the amount of $__________**
2. Please credit my contribution to
   - ❑ GEOSTAR
   - ❑ Greatest Need
   - ❑ GSA Membership Fund
   - ❑ Other:______________________________Fund
   - ❑ I have named GSA Foundation in my Will *(please contact me)*
3. Name ______________________
   Address ______________________
   City / State / Zip ______________________
   Phone ______________________
4. Mail to:
   GSA Foundation
   P.O. Box 9140
   Boulder, CO 80301

cut out or copy

Or donate online at **www.gsafweb.org**

Call for GSA Committee Service

Impact the Future of Geoscience— Serve on a GSA Committee!

2011–2012 COMMITTEE VACANCIES

Deadline to apply or submit nominations: 15 July 2010

GSA invites you to volunteer or nominate one of your fellow GSA Members to serve on Society committees or as a GSA representative to other organizations. Learn more about each committee and access the nomination form at **www.geosociety.org/aboutus/committees/.** You can also download the form and send a hardcopy nomination to Pamela Fistell, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA; fax: +1-303-357-1074; phone +1-303-357-1044 or +1-800-472-1988, ext. 1044; pfistell@geosociety.org. **Terms begin 1 July 2011** (unless otherwise indicated).

COMMITTEE, SECTION, AND DIVISION VOLUNTEERS:

COUNCIL THANKS YOU!

GSA Council acknowledges the many member-volunteers who, over the years, have contributed to the Society and to our science through involvement in the affairs of the GSA. Your time, talent, and expertise help build a solid and lasting Society.

COMMITTEES REQUIRING VOLUNTEERS/NOMINEES:

COMMITTEE	NO. OF VACANCIES	LENGTH OF TERM
Academic and Applied Geoscience Relations (AM, T/E)	one	3 years
Annual Program (AM, B/E)	one	2 years
	one	4 years
Arthur L. Day Medal Award (T/E)	two	3 years
Diversity in the Geosciences (AM, T/E)	three	3 years
Education (AM, B/E, T/E)	one	2 years
	two	4 years
Geology and Public Policy (AM, B/E, T/E)	two	3 years
Joint Technical Program (T/E)	one	3 years, starts 1 Jan. 2011
Membership (B/E)	three	3 years
Nominations (B/E, T/E)	one	3 years
Penrose Conferences and Field Forums (T/E)	one	3 years
Penrose Medal Award (T/E)	two	3 years
Professional Development (T/E)	two	3 years
GSA Public Service Award (T/E)	one	3 years
Publications (AM, B/E, T/E)	one	4 years
Research Grants (B/E, C)	eleven	3 years
Young Scientist Award (Donath Medal) (T/E)	two	3 years

GSA REPRESENTATIVES TO OTHER ORGANIZATIONS

COMMITTEE	NO. OF VACANCIES	LENGTH OF TERM
GSA Conferee to the AAPG Publication Pipeline Committee (B/E, T/E)	one	3 years
North American Commission on Stratigraphic Nomenclature (NACSN) (AM, possibly B/E)	one	3 years, starts Nov. 2011

AM—Meets at the Annual Meeting • B/E—Meets in Boulder or elsewhere
C—Extensive time commitment required during application review period (15 Feb.–15 Apr. 2012) • T/E—Communicates by phone or electronically

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

**PRECEPTOR (TEACHING/CURRICULUM DEVELOPMENT)
EARTH AND PLANETARY SCIENCES
HARVARD UNIVERSITY**

The Dept. of Earth and Planetary Sciences seeks applications for a preceptor. The successful applicant should be well versed on the issues of earth sciences, and have experience in developing, teaching, and supporting sections and labs. A strong doctoral record is preferred. The salary range for this position is $47,900 to $53,100 depending on qualifications and experience. The position is renewable on a yearly basis for up to eight years, contingent upon performance and curricular needs. For greater detail about this position and to apply, visit the EPS Web site: http://www.eps.harvard.edu/icb/icb.do?keyword=k58621&pageid=icb.page252929. Applications should include (i) a cover letter that discusses how this position would fit into the applicant's career trajectory; (ii) the names and addresses of three referees;(iii) a CV; and (iv) a statement of teaching experiences and philosophy. The three letters of recommendation should be submitted separately and at least one letter must discuss the applicant's experience with teaching, administration skills, and other educational work.

Harvard is an Equal Opportunity/Affirmative Action employer. Applications from women and minorities are strongly encouraged.

EDUCATION AND OUTREACH DIRECTOR, UNAVCO

We seek a visionary leader to sustain and enhance the Education and Outreach (E&O) Program at UNAVCO, a university consortium and NSF geodesy facility supporting geoscience research and education. UNAVCO E&O enjoys national recognition for excellence. The program portfolio includes short courses and workshops for research and education, strategic support to scientists in developing broader impacts, in-residence programs for geodesy science community members and educators, professional development in geosciences for K–12 faculty, and RESESS student internships for diversity and workforce development. The successful candidate will lead the UNAVCO community in promoting understanding of geosciences, fostering collaboration between scientific and educational communities, and increasing the number and diversity of students who will become the next generation of geoscientists, while serving on the UNAVCO Senior Management team. Screening begins 11 March 2010, and continues until the position is filled. To learn more and to apply, visit www.unavco.org. UNAVCO is AA/EEO Institution.

**PETROLEUM ENGINEERING
MISSOURI UNIV. OF SCIENCE & TECHNOLOGY
GEOLOGICAL SCIENCES & ENGINEERING DEPT.
ASSISTANT PROFESSOR**

The Geological Sciences and Engineering Department at Missouri S&T anticipates a tenure track faculty opening in Petroleum Engineering at the assistant professor level beginning Fall 2010 or earlier. Successful applicants will have a strong background in mechanical earth modeling and finite element analysis. Candidates must have an earned Ph.D. in Geophysics or Petroleum Engineering that is appropriate to support research and teaching in mechanical earth modeling and related areas, preferably with experience in interdisciplinary settings. Solid oral and written communication skills are essential. Experience teaching mechanical earth modeling and finite element analysis is desirable. Documentation of good teaching is desirable. Experience teaching commercial software packages such as: GOCAD, PETREL, HyperWorks and Abaqus is expected.

The successful candidate is expected to develop a creative and productive research program in mechanical earth modeling and related areas. This research should be independent and interdisciplinary/interdepartmental. Developing contacts with industry and research centers is encouraged. The appointee is expected to teach at the undergraduate level in mechanical earth modeling and related areas, and to develop graduate level course(s) in his/her area of specialization. Supervision of graduate students, student advising, participation in outreach programs, curricular development, and performance of university service are expected.

Missouri S&T is the technological campus of the University of Missouri system. There are approximately 6800 students (5200 undergrads, 1600 grad students) in 65 different degree programs. Missouri S&T was ranked 45th overall and 12th among public universities by American high school counselors in the US News and World Report "America's Best Colleges 2009," and a "Top 20 STEM Research University" by Academic Analytics (January 2008). The Geological Sciences and Engineering department consists of 19 faculty, over 300 undergraduate, and over 50 graduate students in Geology, Geophysics, Geological and Petroleum Engineering.

For additional information (but not to submit applications) contact Dr. Ralph E. Flori, Head of Petroleum Engineering, 318 McNutt Hall, Rolla, MO 65409; reflori@mst.edu; +1-573-341-7583.

Applications should be received as soon as possible and review will continue until the position is filled. Please submit application and vitae to Human Resource Services, Reference Number: R00050335, Missouri University of Science & Technology, 113 Centennial Hall, Rolla, MO 65409, http://hrsifo.mst.edu.

Missouri S&T is an AA/EOE and does not discriminate based on race, color, religion, sex, sexual orientation, national origin, age, disability, or status as Vietnam-era veteran. Females, minorities, and persons with disabilities are encouraged to apply.

The Missouri University of Science and Technology is responsive to the needs of dual-career couples.

Missouri S&T participates in E-Verify. For more information on E-Verify, please contact DHS at +1-888-464-4218. The person selected as the final candidate for a position may be required to provide appropriate verification, prior to the beginning date of employment, that the person possesses the credentials stated on all application materials submitted. Failure to provide such verification may result in the withdrawal of a job offer.

**VERTEBRATE PALEONTOLOGISTS
JOINT APPOINTMENT: ASSISTANT PROFESSOR OF GEOLOGY, GEORGIA SOUTHERN UNIVERSITY AND CURATOR OF PALEONTOLOGY, GEORGIA SOUTHERN UNIVERSITY MUSEUM**

Vertebrate paleontologists are invited to apply for a joint appointment as Assistant Professor of Geology in Georgia Southern University's Department of Geology and Geography and Curator of Paleontology for Georgia Southern University Museum. The full text advertisement is available at http://cost.georgiasouthern.edu/geo/. Screening of applications begins 12 March 2010 and continues until the position is filled. Georgia Southern seeks to recruit individuals who are committed to excellence in teaching, scholarship, and professional service within the University and beyond and who are committed to working in diverse academic and professional communities. Finalists will be required to submit to a background investigation. Georgia is an open records state. Georgia Southern is an AA/EO institution. Individuals who need reasonable accommodations under the ADA to participate in the search process should contact the Associate Provost.

Opportunities for Students

2010 Graduate Student Grant Program, The Spackman Award. The Society for Organic Petrology (TSOP) invites applications for graduate student research grants, the Spackman Award. The purpose of the grants is to foster research in organic petrology by providing support to graduate students from around the world.

Size of the Spackman Award: Monetary awards up to a maximum of $1,000.00 US will be granted. All applicants are invited to enjoy a year's free student membership in TSOP.

Use of the Spackman Award: Grants are to be applied to expenses directly related to the student's thesis program, such as fieldwork, laboratory analyses, etc. A portion (not to exceed 25%) of the funds may be used to attend TSOP Annual Meetings. Funds should *not* be used to purchase capital equipment, to pay salaries, tuition, room, or board during the academic year. Funds must be spent within 18 months of receipt of the award.

Application deadline: TSOP Spackman Award application deadline is 15 May 2010. Grants will be awarded in September 2010.

Detailed information and an application form are on the TSOP Web site: www.tsop.org/grants.htm or applications may be obtained from: Prof Colin Ward, Chair, TSOP Research Committee, School of Biological, Earth and Environmental Sciences, University of New South Wales Sydney, NSW, 2052, Australia; c.ward@unsw.edu.au.

Grad Student Opportunity: Paleontology Field Assistant. The Standing Rock Sioux Tribe's Paleontology Department will be hiring 1–2 graduate students in geology or paleontology to serve as a summer field assistant. The applicant should have prior field paleontology experience and knowledge of field methods. Experience in the Hell Creek Formation a plus. Must be able to work outside in hot, dirty, dusty conditions and carry heavy loads. Must have a valid driver's license. Position begins 24 May and ends 13 August. Start/end dates flexible. Duties include but are not limited to: fossil prospecting, geological mapping, excavating, fossil preparation, camp upkeep, supervising less experienced field assistants, managing and organizing field notes, and acquiring supplies. For more information or to submit a resume, contact Joe Monks at jmonks@standingrock.org.

THE GEOLOGICAL SOCIETY OF AMERICA®

ExxonMobil

GSA–ExxonMobil

BIGHORN BASIN FIELD AWARD

Professional Development Opportunity for Undergraduate Students and Faculty

Award application deadline: 1 April

This award covers all expenses, including airfare, hotel, and meals, for the second annual Bighorn Basin Field Seminar in August 2010.

Field schools have long been a mainstay of geoscience education. They offer an intensive, hands-on experience while using classroom and laboratory knowledge to solve geological problems. The Second Annual GSA–ExxonMobil Bighorn Basin Field Award offers up to 20 undergraduate students and five faculty members a no-cost, high-quality educational experience in the spectacular Bighorn Basin of north-central Wyoming, USA. All transportation, meals, and living expenses are included.

The Integrated Basin Exploration Field School provides an opportunity to study excellent exposures of individual hydrocarbon system play elements, such as source, seal, reservoir, and structure, within a prolific hydrocarbon basin. For more than a century, the Bighorn Basin has been a focus of study because of its exceptional outcrop exposures and subsurface borehole and seismic data. This is not, however, a course on the detailed geology of the Bighorn Basin. Instead, using the Bighorn Basin as a natural laboratory, participants will explore the concepts, methods, and tools of petroleum geoscience. Discussions at the outcrop and in the classroom will focus on how decisions are made with limited data and how critical information is identified in order to evaluate risk versus uncertainty.

The importance of integration across disciplines and scales is stressed throughout the course, which will cover fundamental geoscience skills in structure, stratigraphy, and geochemistry, as well as basin formation, fill, and evolution processes and their interaction to create play elements from regional to prospect scale. Discussions will include consideration of plate motions, paleogeography, sequence stratigraphy, structural deformation, sedimentology, rock properties, subsurface imaging, burial history, and fluid migration. By the end of the field school session, teams will generate play element maps, play summary charts, cross sections, and play fairway maps. The highlight of this course is the presentation of these ideas to the group and the ensuing discussions about how these ideas and play assessments could be further developed.

The school is centered in Cody, Wyoming, surrounded by the Beartooth Mountains, Rattlesnake Mountain, Cedar Mountain, Heart Mountain, and the McCulloch Peaks. Participants will work in teams of four students and one faculty member, and the majority of the course is field-based, supplemented by lectures and exercises in the classroom.

Instructors: Dr. Steve May, Chief Geoscientist, ExxonMobil Upstream Research Co.; Dr. Lori Summa, Senior Technical Consultant, ExxonMobil Upstream Research Co.; Bob Stewart, Supervisor, ExxonMobil Exploration Co.; and Dr. Gary Gray, Technical Team Leader, ExxonMobil Upstream Research Co. These geoscientists represent over 100 years of research in integrated basin analysis, with specific skills in tectonics, geochemistry, structure, sequence stratigraphy, sedimentology, paleontology, hydrocarbon systems analysis, and integrated play analysis.

Applications: To apply, please submit a résumé or curriculum vitae, academic transcripts, two letters of recommendation, and a cover letter by 1 April to http://www.geosociety.org/ExxonMobilAward/. **Questions?** Contact Jennifer Nocerino, jnocerino@geosociety.org, +1-303-357-1036.

Great deals on maps!

Geologic Map of the Western Blue Ridge and Portions of the Eastern Blue Ridge and Valley and Ridge Provinces in Southeast Tennessee, Southwest North Carolina, and Northern Georgia

compiled by J. Ryan Thigpen and Robert D. Hatcher Jr., 2009

This map represents a synthesis of southern Appalachian Blue Ridge and adjacent Valley and Ridge detailed geologic mapping by numerous authors. The western Blue Ridge in this region, which is bound to the northwest by the Great Smoky and Miller Cove–Cartersville faults, and to the southeast by the Allatoona-Hayesville fault, preserves Neoproterozoic-Ordovician synrift, rift-to-drift, and platform rocks deposited along the southeastern Laurentian margin following the ca. 700 Ma rifting and ca. 565 Ma drifting of Rodinia, and Middle Ordovician clastic wedge rocks (Murphy belt) deposited during the Taconic (Ordovician) orogeny. Southeast of the Allatoona-Hayesville fault, rocks of the central Blue Ridge are dominantly composed of high-grade gneiss, schist, and amphibolite. East of the Chattahoochee–Holland Mountain fault, the eastern Blue Ridge (Tugaloo terrane) consists of the Ashe–Tallulah Falls Formation and Grenville basement in the Toxaway and Tallulah Falls domes. Several Middle Ordovician to Mississippian granitic (granodiorite, some tonalite) plutons are also present. This sequence was originally deformed and metamorphosed ca. 455 Ma during the Taconic and then transported westward during the Alleghanian (Permian) orogeny.

MCH097F, 1 color plate (36" × 74") | **sale price $25.00**—folded (sorry, no additional discounts)
MCH097R, 1 color plate (36" × 74") | **sale price $25.00**—rolled (sorry, no additional discounts)

Quaternary fault and lineament map of Owens Valley, Inyo County, eastern California

compiled by D.B. Slemmons, E. Vittori, A.S. Jayko, G.A. Carver, and S.N. Bacon, 2008

This study investigates the active tectonic setting of the Owens Valley graben in the area of the great 1872 earthquake rupture along the Owens Valley fault zone. The area is critical for understanding the tectonics of the southern Walker Lane at the boundary between the Sierra Nevada block and Basin and Range Province. The report compiles known mapped Quaternary faults, provides a context for identifying fault sections, and rationale for delineating major structural blocks in the graben. Many new Late Pleistocene and Holocene faults, particularly west of the 1872 Owens Valley rupture are identified by special low-sun-angle photography. These structures accommodate part of the late Quaternary strain within the eastern California seismic belt.

MCH096F, 2 color plates on 1 folded sheet (30" × 60"), 25 p. text | **sale price $30.00**—folded (sorry, no additional discounts)
MCH096R, 2 color plates on 1 rolled sheet (30" × 60"), 25 p. text | **sale price $30.00**—rolled (sorry, no additional discounts)

Geologic map and cross sections of the Flynn Creek impact structure, Tennessee

compiled by Jonathan C. Evenick and Robert D. Hatcher Jr., 2007

The Flynn Creek impact structure is located in northeastern central Tennessee, on the northeast flank of the Nashville dome. Remapping the structure has better delimited the depositional history and impact structure evolution. The structure contains many features characteristic of complex impact structures: concentric normal faults, central uplift, shatter cones, impact breccia, and a modern internal drainage system. In addition, it contains some distinctive impact-related compressional structures, such as thrust faults and buckle folds in the modified crater rim.

MCH095F, 1 color plate (36" × 66") | **sale price $30.00**—folded (sorry, no additional discounts)

The Geology of Plate Tectonics *by Gregory R. Wessel, 2005*

This chart belongs in every geology classroom and lab! Printed in full color, it attempts to organize the types of plate boundaries and displays them in a useful graphic form. The chart describes geologic features with each type.

MCH059rev, 1 folded sheet (color; 36" × 53") | **sale price $9.95** (sorry, no additional discounts)

$5.00 each

Sorry, no additional discounts.

Late Miocene to Recent Sedimentary Basins of Bulgaria

by Radoslav Nakov, B. Clark Burchfiel, Tzanko Tzankov, and L.H. Royden, 2001

MCH088, 2 b&w plates (30" × 52"; 42" × 37"), with 28-page booklet

Geology of the Nevado de Toluca Volcano and Surrounding Areas, Central Mexico

by A. García-Palomo, J.L. Macías, J.L. Arce, L. Capra, V.H. Garduño, and J.M. Espíndola, 2002

MCH089, 1 color map (36" × 38"), with 26-page booklet

$10.00 each

Sorry, no additional discounts.

Geological Map of the Northern Main Ethiopian Rift

by Tsegaye Abebe, Piero Manetti, Marco Bonini, Giacomo Corti, Fabrizio Innocenti, and Francesco Mazzarini, 2005

One of the main objectives in unraveling the complex development of a continental rift is to set on the structural evolution and magmatism of the rifting system. In this work we present a new geological map of the Northern Main Ethiopian Rift, compiled using data from field work, analysis of aerial photographs, satellite images, topographic maps, and petrographic and geochemical analyses on rock samples. The new data provided an insight on the timing of rift activity and its tectonomagmatic evolution, evidencing a two-stage evolution of deformation and associated magmatic activity from a Pliocene orthogonal extension to a Quaternary oblique one.

MCH094F, 1 folded sheet (color; 31" × 40"), 20 p. text

Geology of the Scott-Reedy Glaciers Area, Southern Transantarctic Mountains, Antarctica

by M.B. Davis and D.D. Blankenship, 2005

MCH093F, 1 folded sheet (color; 46" × 26")

An Earth Scientist's Periodic Table of the Elements and Their Ions

by L. Bruce Railsback, 2004

MCH092F, 1 folded sheet (color; 36" × 76"), 7 p. text

Geologic Map of the Batesburg and Emory Quadrangles, Lexington and Saluda Counties, South Carolina

edited by Donald T. Secor Jr. and Arthur W. Snoke, 2002

MCH091, 1 folded plate (color; 36" × 57"), 32-page booklet

Geology of Kangmar Dome, Southern Tibet

by Jeffrey Lee, William S. Dinklage, Yu Wang, and Jing Lin Wan, 2002

MCH090, 1 folded sheet (b&w; 33" × 52")

www.geosociety.org/bookstore

GSA SALES AND SERVICE P.O. Box 9140, Boulder, CO 80301-9140, USA
+1.303.357.1000, option 3 • Toll-free 1.888.443.4472 • Fax +1.303.357.1071

THE GEOLOGICAL SOCIETY OF AMERICA®