WEST TEXAS GEOLOGICAL SOCIETY

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El Capitan Peak shelf deposits (background) and muddy Brushy Canyon Formation basinal deposits (foreground) have generally been interpreted as deep water turbidites. Higgs (this issue) discusses evidence for an alternative interpretation. See Figure 5 for a detailed explanation.

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Sonora Caverns Cave Popcorn taken: 5-8-2014 Photo by: Mike Raines

From the

President

Dave Cromwell

President's letter:

As we end the 2014-2015 fiscal year of the WTGS with the annual awards banquet 21 May, I would like to thank everyone who helped make this year successful. We had a good Board of officers and committee members that worked hard to give you, the members, educational and social opportunities.

We started in June by moving the WTGS office to our newly remodeled building on the Midland Energy Library campus. July saw visits to the Boy Scout ranch to help them with the geology merit badge. The August scholarship skeet shoot had a great turn-out and over $18,000 was split with the PBGS. The annual fall symposium had over 300 attendees. I think that everyone enjoyed the pre-meeting ice breaker. The core workshop and golf tournament were also popular events the day after the talks. In October we had the fall social at Frank Suttles' house. It was a first class event by the Suttles Logging team. The Society is going to miss Frank in many ways and I will always cherish my friendship with him. We finished the year with a holiday/open house at the new WTGS headquarters and had lots of good food.

We began 2015 in January with the earth science presentations to the MISD 5th and 6th graders. As always it was enjoyable. We then began planning for the short course given by Dr. Peter Scholle in March. His presentation was an excellent overview of carbonate mudstones and was well received by the over 100 attendees.

April is somewhat a blur as I had my gall bladder removed. Everyone tells me that I won't miss it --- hope that they are right!

Mark your calendar for May: Riley's Logging will sponsor a social on Friday 15 May. The WTGS Awards banquet will be 21 May at the Petroleum Club. On 28 May the WTGS and PBS-SEPM will have a special joint luncheon meeting with Alton Brown discussing the geology of the ancient pyramids of Egypt.

There are several things that we are still working to achieve: a hard copy directory of the membership and a one-day field trip that may or may not happen in May.

The year has had some very interesting, diverse, educational and even entertaining luncheon speakers. Thanks Curtis, great job.

As we transition to the new fiscal year, I would like to congratulate the new officers of the WTGS. Please support them in their endeavors to guide the Society.

President: Dave Thomas

President-elect: Jeff Bryden

1st Vice-president: Dave Osterlund

2nd Vice-president: Andrew McCarty

Secretary: Holly Warmke

Treasurer: Wendy Roberson

I hope that we, as an executive committee, have followed through with my initial promise to you, the members, to be proud of this organization!

Thanks for the honor of serving as your president,
Dave Cromwell

2015 - 2016 WTGS Executive Board

We would like to congratulate the new upcoming board members! Thank you to all who took the time to vote!

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WTGS

Luncheon

Tuesday, May 12th 2015

Midland Center - Corner of Wall and Main, downtown Midland
Lunch : 11:30 AM **Cost** : $15
Make Reservations with WTGS Office (432-683-1573)

Steve Sonnenberg, PhD

Petroleum Geology of the Niobrara Formation, Silo Field, Wyoming

1 Department of Geology and Geological Engineering, ColoradoSchool of Mines

ABSTRACT

The Silo Field is located in the northern part of the Denver basin. Production is from the fractured Niobrara Formation at depths ranging from 7600 to 8500 ft (2318 to 2593 m). Cumulative production from 40 vertical and 68 horizontal wells at Silo is in excess of 10.4 million barrels of oil and 8.9 billion cubic feet gas. Recent drilling success with horizontal wells and multistage-fracture stimulation suggests much greater future production. Initial potential from the first new horizontal well is 1075 bbl of oil/day (Atlas 1-19H).

The dominant lithologies of the Niobrara are limestones (chalks) and interbedded calcareous and organic-rich shales. Niobrara thickness ranges from 280 to 300 ft (85 to 92 m). Four limestone intervals, averaging 30 ft (9.2 m), and three intervening shale intervals (averaging 47 ft or 14.3 m) occur regionally and are easily recognized on geophysical logs. The lower limestone is named the FortHays, and the overlying units are grouped together as the Smoky Hill member. Limestone beds in the Smoky Hill are informally named the A, B, and C intervals in increasing depth order. The fractures are concentrated in the more brittle limestones. The main production is from the middle limestones (B interval) of the Smoky Hill. Shows and production also come from the A, C, and FortHays chalk intervals in older vertical wells which suggest they may be future targets of horizontal drilling. The current target of horizontal drilling is the B chalk interval. The intervening shales have high organic matter content and served as source beds and seals.

Open fracture systems are essential to Niobrara production because little matrix porosity exists in the limestones. Open fractures in the field are very consistent and are oriented N25-40W. The origin of the fractures is coincident with a similar trending structural monocline present at the Niobrara level and Permian salt dissolution edge. The monoclinal flexure model of fracture formation best fits available data for Silo field.

High resistivities are observed in limestone beds at Silo. These resistivity anomalies appear to be related to the presence of a large hydrocarbon accumulation delineated by isoresistivity mapping.

Factors present at Silo will serve as a model for future Niobrara production in the RockyMountain region. These factors include (1) mature source rocks interbedded with brittle limestone; (2) open fractures to form the reservoir; (3) resistivity anomalies indicating accumulation; and (4) technology to efficiently produce the reservoir.

SPEAKER: Steve Sonnenberg, PhD

Dr. Stephen A. Sonnenberg is a Professor and holds the Charles Boettcher Distinguished Chair in Petroleum Geology at the Colorado School of Mines. He specializes in unconventional reservoirs, sequence stratigraphy, tectonic influence on sedimentation, and petroleum geology. A native of Billings, Montana, Sonnenberg received BS and MS degrees in geology.

Dr. Stephen A. Sonnenberg is a Professor and holds the Charles Boettcher Distinguished Chair in Petroleum Geology at the Colorado School of Mines. He specializes in unconventional reservoirs, sequence stratigraphy, tectonic influence on sedimentation, and petroleum geology. A native of Billings, Montana, Sonnenberg received BS and MS degrees in geology from Texas A&M University and a Ph.D. degree in geology from the Colorado School of Mines. He has over twenty-five years experience in the industry.

Steve has served as President of several organizations including the American Association of Petroleum Geologists, Rocky Mountain Association of Geologists, and Colorado Scientific Society. He also served on the Colorado Oil and Gas Conservation Commission from 1997-2003 and was the Chair of the Commission from 1999-2003.

He is the recipient of the Young Alumnus Award, Outstanding Alumnus Award, and Mines Medal from the Colorado School of Mines, Distinguished Achievement Medal from Texas A&M University, distinguished service awards from AAPG and RMAG, and honorary membership awards from AAPG, RMAG and the Colorado Scientific Society. In 2013, he was awarded the Halbouty Medal from AAPG.

Brushy Canyon Formation (Permian), Delaware Basin, USA and Look-alikes on Three Continents: 'Outcrop Analogs' for Deep-sea-turbidite Oilfields?

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Abstract

Despite its previous shallow-water interpretation, oil companies exploring and developing the Brushy Canyon Formation (Permian) now rely on a popular deep-sea-fan model. Moreover, many authors recommend the Brushy as an 'outcrop analog' for deep-sea-turbidite reservoirs in costly offshore exploration-production areas (e.g., passive margins of Africa, Brazil, Gulf of Mexico, where economic losses from using incorrect analogs can reach billions of dollars), despite the Brushy's very different tectonic setting (foreland basin) and numeorus features suggesting relatively shallow-water deposition in a low-salinity 'Lake Brushy' (e.g., lack of marine fossils other than reworked ones; HCS in many of the event beds). The Brushy qualifies as flysch (synorogenic, turbiditic, and thick, c. 300 m) and closely resembles other famous flysch formations (e.g. Annot, Bude, Cerro Toro, Hecho, Jackfork, Laingsburg, Marnoso-arenacea, Ross, Skoorsteenberg). Individual Brushy event beds are typically fine grained, non-laminated and ungraded (except the top 1-2 cm), suggesting turbidity currents that were steady, depletive, too slow for traction and sustained (weeks?), enabled by easy underflow in low-salinity lake water, i.e. these are megaflood hyperpycnites. Beds with HCS are interpreted as storm-wave-modified hyperpycnites. An inner-Brushy belt of supposed "deep-sea-slope muds" containing incised "slope channels" is reinterpreted here as a stack of delta-slope clinothems, each < 15 m thick, separated by ravinement sequence boundaries and containing low-sinuosity incised distributaries (ending at delta-slope gullies) with hyperpycnite fill. The delta(s) prograded onto an outer-Brushy shelf (inherited from earlier passive margin) facing a SE-subducting remnant ocean cut off from the world ocean by the Marathon salient (of Gondwana) colliding early against Euramerica, raising a sill (Diablo Platform), isolating an 'ocean lake' freshened by river inflow. Inner-Brushy delta progradation during lake highstands (glacioeustatically-driven, over the sill, also raising lake salinity) reciprocated with lowstand deposition of hyperpycnites on the Brushy shelf (delta bypassed due to easy underflow during low-salinity lowstand). Limestone-block conglomerates in the basal innermost Brushy are interpretable as debrites and rockfall breccias derived from the walls of drowned gorges (rias) into which the rivers feeding the Brushy debouched from caves in the limestone hinterland. Fusulinids in Brushy sand beds are reworked from cave- and ria walls, while the Brushy's lack of coarse sand and plant leaves reflects removal of tractional sand fallen into cave fissures, and trapping of vegetation in logjams at cave narrowings. The new Brushy shelf-hyper-pycnite model is crucial for Brushy exploration and development (placement of wells and perforations; reservoir flow modeling; reserves calculations) since predicted sand-body geometries (incised distributaries feeding point-sourced shelfal hyperpycnite ovoids and shelf-indenting submarine canyons) differ greatly from those forecast by the popular deep-sea-fan model (slope channels, suprafan leveed channels, lateral splays, distal lobes). Likewise, the Brushy is highly misleading as an 'outcrop analog' for passive-margin deep-sea-turbidite reservoirs around the world.

Introduction

The Brushy Canyon Formation belongs to the Delaware Mountain Group (lower Guadalupian, Middle Permian; King, 1948) of the Delaware Basin, a foreland sub-basin of the Marathon salient of the Ouachita orogen (Ross, 1986). The Brushy qualifies as flysch (i.e. orogenically related turbiditic formations 100s-1000s m thick), and closely resembles several famous formations historically dubbed flysch around the world, e.g. Jackfork (van Waterschoot van der Gracht, 1931), Cerro Toro (Cecioni, 1957), Annot (Bouma, 1962), Laingsburg and Skoorsteenberg (Truswell & Ryan, 1969; Johnson et al., 1997), Marnoso-arenacea (Ricci-Lucchi, 1969), Hecho (Rupke, 1976) and Bude (Beach, 1977), and also the Ross Formation, whose similarity to the Bude was highlighted by Higgs (2004; first pointed out to me in 1983 by my doctoral supervisor, Harold Reading). All of these formations are orogenically external- or "miogeosynclinal flysch," as opposed to internal- or "eugeosynclinal flysch" (Abbate et al., 1970 terminology; Higgs, 2014a). External-flysch folding and faulting can range from negligible (e.g., Skoorsteenberg) to intense (e.g., Bude), depending on how far the orogeny's deformation front could advance. Evidence is emerging that all external flysch is shelfal (Higgs, 2014a, 2015a). All of the formations listed above were deposited along collisional belts of great length (1000s km), amenable to early collision at promontories, isolating remnant-ocean sectors as 'ocean-lakes' (Higgs, 2014a, 2015a, b).

The Brushy, comprising mainly turbidite-like sandstones and background mudstone (largely silt-grade), is important not only as an oil and gas producer (e.g., Montgomery et al., 1999), but also because numerous authors recommend it as an outcrop analog for deep-sea turbidite reservoirs, especially those beneath passive margins like the Gulf of Mexico, Africa and Brazil (e.g., many articles in Nilsen et al., 2007; see below). However, the Brushy's paleo-water depth is historically controversial (10s versus 100s m; summary in Harms and Brady, 1996). The popular deep-sea-fan model (Jacka et al., 1968; Beauboeuf et al., 1999; Carr and Gardner, 2000) is questioned here, with profound implications for prediction of sand distribution, geometry and architecture, essential for:

(1) optimum borehole placement (producers, injectors; vertical, horizontal);
(2) positioning of perforations;

(3) choice of reservoir-model input parameters; and
(4) economic evaluations (prediction of reserves and production rates). These predictions are vital both in the Brushy itself, and in supposedly analogous turbidite reservoirs of definite deep-sea origin beneath passive margins where, due to high operating costs (deep water, deep burial), the use of improper analogs risks billions of dollars in (A) non-optimum borehole placement and (B) unrealistic forecasts of production and reserves, resulting in unwarranted field development or abandonment (Higgs, 2009a).

This contribution is based on
(1) a literature review,
(2) three days spent by me in 2009 studying roadcuts along U.S. Highway 62-180, in and near Guadalupe Mountains National Park, and
(3) my intimacy with the Brushy-look-alike Bude Formation (Pennsylvanian, UK; Higgs, 1991, 2004, 2008).

Location maps, stratigraphic tables and cross sections relevant to the Brushy, abundant in the literature (see especially Beauboeuf et al. [1999] and Scholle [2000]), are not repeated here.

Shallow- vs deep-water Brushy published models

Early authors interpreted the Brushy environment as shallow and wave-influenced (King 1948; Newell et al. 1953). A later model, now widely accepted, of slope channels feeding deep-sea basin-floor fans (Jacka et al 1968; Beauboeuf et al., 1999; Carr and Gardner, 2000; Gardner and Borer, 2000; Gardner et al., 2003), was based on:
(1) observation that sands are entirely channeloid in the inner-Brushy outcrop (up-paleocurrent) but both channeloid and sheet-like in the outer Brushy;
(2) conviction that these sand bodies compare well with those of modern Californian deep-sea fans; and (3) perceived lack of wave-formed sedimentary structures, despite King's (1948) statement that "The marks in the Brushy Canyon formation appear to have a symmetrical cross section, which indicates they are oscillation rather than current ripple marks."

Beauboeuf et al. (1999, p. 1) stated that Brushy water depths were "on the order of 400-600 m (King, 1948)." This is a misquotation. King (1948) in fact said:
(1) "The preceding ... black lime-stone facies ... show evidence of ... quiet and *perhaps* deep water, whereas ... Brushy Canyon formation ... is probably a shallow - water deposit" (my italics); and
(2) "at the beginning of Guadalupe time the Delaware Basin became an area of shallow water." King did estimate deep water (1,000 ft) *for the top of the Bell Canyon Formation* (the next-but-one formation above the Brushy), based on the present-day relief (adjusted for post-Bell regional tilting) between the Capitan "reef" and the end-Bell (Lamar) "basin floor," but this overlooks drastic differential compaction between the Capitan carbonates and the organic-rich siltstones that dominate the Bell (see below).

Evidence for Brushy shallow-water lacustrine deposition

Seven Brushy characteristics collectively negate the deep-sea-fan model and suggest deposition on a storm-influenced lake shelf:
(1) Indigenous marine body fossils are absent. Many sandstone beds contain fusulinids, commonly oriented (King, 1948), interpreted by Scholle (2000) as reworked from older rocks. Indeed, of the four species cited by King (1948) in the Brushy, *Parafusulina rothi*, *P. maleyi*, *P. sellardsi* and *P. lineata*, the first two also occur in the underlying Cutoff Formation (Glenister et al., 1991), the third probably occurs in the Cutoff's proximal equivalent, the lower San Andres Formation (sp. aff. *P. sellardsi* reported by Hayes, 1959), and the fourth is, in fact, confined to the Cherry Canyon Formation above the Brushy (Glenister et al., 1991). Diverse other marine fossils occur in Brushy sandstone beds but are abraded (King, 1948; Newell et al., 1953), again suggesting reworking from older strata. Lack of reported *in situ* marine fossils or unequivocally marine trace fossils (see below) suggests deposition in a lake, named "Lake Brushy" by Higgs (2014b). Nevertheless, thin (cm-dm) bands with indigenous marine fossils may yet be discovered and would be unsurprising, reflecting eustatic rises high above the lake sill (see below; see fig. 20 of Higgs 1991). Rare impressions of plants or soft-bodied animals were reported in the Delaware Mountain Group by Harms and Williamson (1988). Unidentified Brushy(?) fossils photographed by myself (Figure 1) are possibly indigenous soft-bodied organisms (readers' opinions are invited, by email please);
(2) Trace fossils are relatively scarce. I saw no vertical burrows during three days of close scrutiny, suggesting that trace fossils are mostly horizontal and thus not readily exposed in the (mainly) sub-horizontal Brushy strata. Dominance of horizontal traces is characteristic of both the lacustrine *Mermia* ichnofacies (Buatois and Mángano, 1995) and the deep-marine *Nereites* ichnofacies. On one of the scarce Brushy bedding-plane exposures, I saw a single ichnofossil specimen, possibly *Thalassinoides* or *Treptichnus* (Figure 2), the latter being typical of the *Mermia* ichnofacies. Harms and Williamson (1988, p. 303) identified bedding-parallel traces in siltstones of the Delaware Mountain Group as "*Helminthoida* of the *Nereites* ichnofacies," but these could alternatively be *Helminthopsis* or *Helminthoidichnites*, both common in the *Mermia* ichnofacies. Bohacs et al. (2000) stated that Brushy and lower Cherry cores contain "a moderate diversity and abundance ichnofossil assemblage with moderate depth of tiering" (implying vertical or oblique burrows), but unfortunately they did not name the ichnogenera;
(3) Paleocurrents in Brushy outcrops were from the northwest (Zelt and Rossen, 1995; Beauboeuf et al., 1999), i.e., from the craton rather than the orogen, suggesting that orogen-derived turbidity currents were intercepted (blocked) by a deep-water trough lying to the southeast, interpreted here as a remnant ocean, lying on remnant-ocean lithosphere that

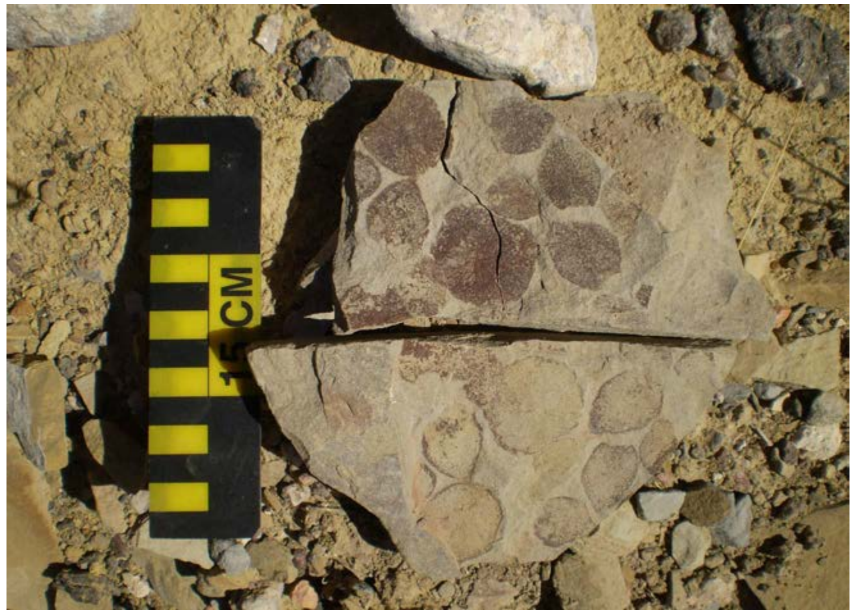

Figure 1. Impressions of possible fossils, looking down on a parting surface in parallel-laminated siltstone (mirror-image part and counterpart). Float block, beside roadcut in Brushy Canyon Formation at Stop II-3a of Scholle (2000), U.S. Highway 62-180, Guadalupe Mountains National Park. The non-overlapping nature of these features is suggestive of in situ soft-bodied organisms rather than drifted plant leaves. The author would value readers' opinions (please email).

was being consumed at the Marathon subduction zone. This, in turn, implies Brushy deposition on an adjacent shelf (cf. Higgs, 1991, 2004, 2008), in the northwest, inherited from the pre-cursor passive margin;

(4) Many sand beds have low-asymmetry ripples (King, 1948; Newell et al., 1953; slide 23 of Higgs 2014b, v. 2), suggesting that deposition involved waves. Both King (1948) and Newell et al. (1953) interpreted the Brushy as shallow-water deposits. Brushy near-symmetrical ripples were attributed to wave-dominated combined flow by Harms (1969), whose figure 17 shows ripple crests bifurcating, diagnostic of wave action (Reineck and Singh, 1980);

(5) Many beds show structures interpretable as hummocky cross stratification (HCS) and swaley cross stratification (SCS), implying that deposition involved storm waves (Higgs 2011). The supposed HCS is commonly faint (Figures 3-4; in contrast see slide 21 of Higgs 2014b, v. 2), attrib-utable to blurring by earthquake-induced liquefaction (Higgs, 2004). Susceptibility to liquefaction may reflect non-marine pore waters, inhibiting very early carbonate cementation (contrast marine sands; Molenaar, 1990). The HCS and SCS were described or interpreted by previous workers as “low-angle lamination,” “lenticular sandstone,” “cross bedding,” “trough cross stratification,” “plow and fill,” and “Helmholtz waves” (Zelt and Rossen, 1995; Beauboeuf et al., 1999; Gardner and Borer, 2000), and as “plow-and-fill ... (that has) ... been misinterpreted as ... hummocky to swaley cross-stratifica-tion” (Gardner and Sonnenfeld, 1996, p. 31). “Plow and fill” with steep lamina-dips (fig. 8f of Gardner and Borer, 2000) is possibly SCS that has undergone soft-sediment deformation (*in situ* foundering) by earthquake-induced liquefaction;

(6) Numerous sand beds have sharp upper surfaces in the form of undulatory mud-draped scours with irregular, low relief (cm-dm; see slide 24 of Higgs, 2014b, v. 2), characteristic of storm beds (Walker et al., 1983, fig. 1 ideal bed); and

(7) The basin-fill architecture contradicts a deep-sea-slope and basin-floor-fan setting. Inner-Brushy mudstones (with sand-filled channels) interfinger with outer-Brushy sheet-like sands (e.g., fig. 4 of Beauboeuf et al., 1999) whereas, in the classic Exxon ‘slug’ diagram (e.g., Van Wagoner et al., 1988), deep-sea-slope muds downlap onto a base-of-slope fan (as inferred also in fig. 11 of Beauboeuf et al. 1999). Moreover, the same Brushy mudstones onlap in the opposite direction (craton-ward) onto an unconformity (Beauboeuf et al., 1999, fig. 4), raising the question of how the supposedly deep-water upper slope remained bare (non-depo-sitional) while onlap was in progress below (see slide 13 of Higgs 2014b, v.2).

In summary, the seven foregoing characteristics are irreconcilable with the Brushy deep-sea-fan model. Instead, deposition on a lacustrine ‘Brushy shelf’ is proposed. The evidence for waves implies deposition above storm wave base, whose depth might not have exceeded 150 m in a limited-fetch lake (Higgs 2004). The lake’s low salinity (humid catchment; see below), hence low density, favored hyperpycnal flows (river-fed turbidity currents), especially during catastrophic floods.

Paleoclimate

During Brushy time, the Delaware Basin lay within 10° of the equator (Scotese and McKerrow, 1990; Scotese, 2002). Evaporites, signaling aridity, occur stratigraphically close below and above the Brushy (Yeso and upper San Andres Formations; Kerans et al., 1994). However, an overall humid climate for Lake Brushy and its catchment is sug-gested by: (A) terrestrial organic matter, including conifer pollen, in background carbonaceous siltstones (see below; Harms and Williamson, 1988; Sageman et al. 1998); (B) coeval karstification of the adjacent NW land area (Kerans et al., 1994; Stoudt and Raines, 2004); and (C) fossil leaves (Hill, 1999) in Brushy-equivalent strata near the southern basin margin (Word Formation; Lambert et al., 2007). Interpretation of Lake Brushy as hyposaline (as opposed to hypersaline), and Brushy event beds as hyperpycnites, is consistent with a humid climate. The scarcity (absence?) of reported plant fragments longer than 1 cm in the Brushy is attributed here to the sediment-supplying rivers occupying, along part of their lower reaches, caves that trapped detrital vegetation (see below).

Lake Brushy tectonic origin, physiography and hydrology

Due to the great length (1000s km) of the Euramerica-

Figure 2. Poorly exposed branching burrow (to right of scale; possibly *Thalassinoides* or *Treptichnus*), looking down on a parting surface in parallel-laminated siltstone, Brushy Canyon Formation, eastern roadcut of the two cuts at Stop II-3 of Scholle (2000), U.S. Highway 62-180, Guadalupe Mountains National Park.

Gondwana collision belt (Scotese and McKerrow, 1990), of which the Marathon-Ouachita segment is just a part, early collision of continental salients against the opposing continent would have pinched off sectors of the shrinking (subducting) Phoibic-Rheic Ocean, severing them from the world ocean by raising a tectonic sill, limiting entry of ocean water, forming "ocean lakes" (Higgs, 2014a; see slides 31-34 of Higgs, 2014b, v.2) like Lake Brushy which, whenever glacioeustatic sea level fell below the spill point, were kept brimful and diluted by river inflow (if this exceeded evaporation), preventing forced emergence of shelves (Higgs, 1991, 2004). The Quaternary Black Sea is partially analogous (ocean-floored; currently hyposaline), except that evaporative drawdown (exposing the shelves) occurred at lowstands, when eustatic sea level was below the sill (Major et al., 2002).

Just prior to Brushy time, deposition on the Delaware Basin NW margin comprised lower San Andres Formation carbonates, deepening SE into the shalier Cutoff Formation (Kerans et al., 1994). The Brushy onlaps onto the Cutoff (Kerans et al., 1994). A shelf-slope physiography has been inferred for the lower San Andres-Cutoff system (e.g., fig. 4 of Beauboeuf et al., 1999), partly based on the currently observable relief. However, the relief is largely due to later flexure (see below), therefore a lower San Andres-Cutoff *ramp* is considered more likely here. In the Brushy outcrop area, the ramp underwent pre-Brushy differential (forebulge?) uplift, based on three observations: (1) inner ramp karstification (Kerans et al., 1994), indicating subaerial exposure, reaching basinward at least as far as the upper Brushy onlap edge (Gardner and Sonnenfeld, 1996); (2) a mid-ramp structural steepening, the Bone Spring Flexure (BSF; King, 1948), situated immediately basinward of known karst effects, but interpreted here to have become subaerial too, and later onlapped by the lower Brushy; and (3) basinward of the BSF, a thick (c. 100 m) interval of slide deposits forming the upper Cutoff (Amerman et al., 2006), interpreted here as sliding off the rising, steepening BSF (while still submerged), consistent with the Cutoff's absence in the flexure area and its reappearance farther landward (King, 1948; see figs 3 and 4 of Beauboeuf et al., 1999). The former outer ramp remained under water during BSF growth, but became shallower by slide emplacement and possibly also by tectonic upwarping.

Based on the foregoing inferences, the base of the Brushy is interpreted here as a tectonic sequence boundary, comprising a distal, subaqueous con-formity (overlain by the Pipeline Shale Member; cf. fig. 4 of Beauboeuf et al., 1999) passing northwest into a subaerial unconformity (proximal, sub-Brushy karst; Gardner and Sonnenfeld, 1996) onlapped by younger Brushy strata.

Bordering the Delaware Basin in the southwest was the Diablo Platform (fig. 10 of Ross, 1986), also inferred here to have undergone uplift then (during BSF growth), by early collision of the Marathon salient, forming Lake Brushy's sill, restricting the western connection to the paleo-Pacific Ocean, converting the preceding Cutoff marine gulf into a silled, "sea-level lake" (Goldring, 1978; Higgs, 1991). The Cutoff's upper contact is "commonly littered with ammonites" (Carr and Gardner, 2000), suggesting mass mortality, consistent with river inflow lowering the new lake's salinity. Either the Hovey Channel or the Diablo Channel (Hill, 1999), crossing the Diablo Platform (lake sill), was the site of the lake's outlet river, flowing over the lake spillpoint to the ocean. Whenever glacioeustatic

Figure 3. Brushy Canyon Formation sandstone. 15 cm scale in shadow in crevice at top. Faint lamination shows three features suggestive of hummocky cross stratification: (1) low-angle dips (< 15°); (2) low-angle discordance internally (right side, middle); and (3) local upward con-vexity (left side, middle). The faintness is attributed to blurring caused by earthquake-induced liquefaction. For location see Figure 5 caption.

(Jacka et al., 1968) sea level fell below the spillpoint, Lake Brushy remained perched at the spillpoint, topped up by river inflow and freshening, potentially turning completely fresh (fig. 20 of Higgs, 1991). When rising sea level overtopped the sill sufficiently, a wedge of ocean water intruded up the outlet channel, increasing the lake salinity (cf. modern Black Sea and Bosporus Strait; Higgs, 1991). Extreme rises (if any) may have turned Lake Brushy briefly into a marine gulf, with indigenous marine fossils, as yet unproven in the Brushy, but known in rare, thin (cm-dm) bands in the look-alike Bude and Ross formations (Higgs, 1991, 2004; see below).

Details of main Brushy facies associations

Further details of the Brushy's two main facies associations at outcrop are as follows, based on published descriptions and my own observations.

1. Inner Brushy mudstones with sand-filled channels. This association dominates the proximal sector of the Brushy outcrop, forming an onlapping belt a few kilometers wide (e.g., fig. 4 of Beauboeuf et al., 1999). Channels are incised, non-leveed, and contain amalgamated sandstone event beds. Channels are individually narrow (10s-100s m) and shallow (< 10 m), but can also occur as thicker (10s m), wider, composite channels (Beauboeuf et al., 1999; Gardner et al., 2003). Sinuosity is low (e.g., fig. 10 of Beauboeuf et al., 1999; Beauboeuf et al., 2007; Pyles et al., 2010). There is no unequivocal evidence for levees (Harms, 1974).

2. Outer Brushy sand-filled channels, tabular sands and heterolith. This association comprises:

(A) amalgamated-sand bodies 0.5-10 m thick that are sheet-like at the scale of individual exposures (i.e., lateral extent 10s-100s m at least);

(B) sheet-like heterolith (i.e., mudstone with sandstone event beds thinner than 30 cm); and

(C) sand-filled channels that can be welded to the base of amalgamated sheets (cover photo, Figure 5 and Figure 6) or incised into the top.

The channels have levees according to some authors (Zelt & Rossen, 1995; Beauboeuf et al., 1999) but not others (Gardner et al., 2003). Paradoxically, even in the thickest (5-10 m) amalgamated-sand bodies, the constituent beds are only thin (5-40 cm) and usually only very-fine- to fine-grained. Such "advanced amalgamation" (Higgs, 1991) is attributable to low-salinity bottom mud, weakly cohesive due to methane bubbles and/or weak ionic attractions (Higgs, 1991, 2004), easily resuspended by the next sand-delivering event. Low relief (dm) undulatory scours draped by a thin (mm-cm), commonly discontinuous mud layer can occur within sand sheets (Figure 6). Amalgamated sand sheets can deamalgamate laterally (cf. "frayed" sheets of Higgs, 1991), i.e., each component sand bed occupies and overspills a shallow (0-30 cm), steep-walled, flat-floored minichannel cut in mud. Successive mud pinchouts (minichannel walls) may occupy a surprisingly narrow belt (< 10 m; e.g., fig. 5.2 of Beauboeuf et al., 1999), indicating that successive flows followed essentially the same track and had similar velocity structure.

Details of Brushy event beds

Sandstone event beds in both the inner- and outer-Brushy facies associations are of two kinds, almost invariably finer than medium grained:

(1) Bouma type, mostly Ta or Tab, suggesting deposition from turbidity currents, probably river-fed (hyperpycnal) flows in view of the evidence cited above for low salinity (easy underflow). The lack of both grading and lamination in the Bouma A division (globally) has generally been attributed to brief deposition (< 1 hr; Allen, 1991), with parallel lamination suppressed by rapid fallout (Arnott and Hand, 1989) from a turbidity current otherwise fast enough for traction. However, this mechanism has been discredited (Leclair and Arnott, 2005). An alternative model, consistent with the A division's universal medium-or-finer grain size (e.g., Lowe, 1982), is slow fallout, from a steady-and-depletive turbidity current (hence lack of grading; Kneller, 1995), sustained enough to deposit a decimetric bed (days-months?), and flowing too slowly, at any given position (proximal-distal), to move tractionally the particular grain-size settling there (cf. Sundborg, 1967). Fusulinids, where present in Brushy sandstone beds, are interpreted here to have been rolled and co-deposited with sand falling out of suspension. Sidelap of channel-filling sand beds and lack of levees (Harms,

Figure 4. Brushy Canyon Formation amalgamated sandstone beds (upper half; note faint, sub-horizontal lamination to right of center), overlying a heterolithic interval of thinner sandstones interbedded with mudstone (little contrast in weathering color). The central bed (touching the scale) is of fine- or very-fine grained sandstone and has an undulating top, interpretable as two hummocks, based on: (1) evidence for hummocky cross stratification elsewhere in the Brushy (e.g. Figure 3); (2) lack of strong asymmetry; (3) deci-metric wavelength; and (4) centimetric amplitude. The lack of internal lamination discernible from this distance is attributed to blurring caused by seismically induced liquefaction. Eastern roadcut of the two cuts at Stop II-3 of Scholle (2000), U.S. Highway 62-180, Guadalupe Mountains National Park.

1974) both suggest that flows were thin. The Harms (1974) model of Brushy sand-bed deposition by shelf-derived saline density currents contradicts the evidence, discussed above, for a humid climate; and

(2) Beds with HCS (usually blurred) and / or low-asymmetry ripples, interpretable as storm-wave-modified hyperpycnites (Myrow et al., 2002; Pattison, 2005). These beds are interspersed with Bouma beds, without obvious predictability.

Background mudstone

The mudstone in both the inner- and outer-Brushy facies associations is silt-dominated and mainly comprises alternating laminae (mm and sub-mm) of silt and carbonaceous matter (Harms, 1974; Harms and Williamson, 1988), interpreted here as seasonal couplets. Wet-season silt supplied by river-fed mesopycnal (interflow) or hypopycnal (surface) plumes was spread shelf-wide by wind-driven circulation of the ocean-lake's epilimnion (including entire shelf water column), flowing too fast for clay to fall out. In contrast other authors have attributed the Brushy's scarcity of clay to a clay-poor provenance (Newell et al., 1953), or to aridity such that wind-blown clay overflew the basin while silt fell out, and sand was delivered from eolian coastal dunes via slump-generated turbidity currents (Fischer and Sarnthein, 1988). However, sand angularity (Newell et al., 1953; photomicrographs in Montgomery et al., 1999, Justman and Broadhead, 2000; Shew, 2007a, b) contradicts the eolian model, as does the humid climate inferred above.

Brushy mudstone lacks carbonate laminae, whose photosynthetically induced precipitation is common in lakes (Kelts and Hsü, 1978). This absence suggests limited phytoplankton, reflecting either poor light penetration due to suspended mud, and / or evolutionary failure related to the unusual lake salinity (brackishness) or to the global Late Paleozoic marine "phytoplankton blackout" (Riegel, 2008). Dominance of Type II kerogen (Justman and Broadhead, 2000), potentially all terrigenous (palynomorphs; macerated leaves), is consistent with scarcity of phytoplankton.

Organically richer siltstone marker beds (10 to > 200 cm thick; cover photo) interpreted as condensed sections (Sageman et al., 1998; Beauboeuf et al., 1999) are further interpretable as maximum flooding intervals corresponding to the highest glacioeustatic highstands.

Scarcity of slump beds

Paucity of beds interpretable as slumps (Beauboeuf et al., 1999) is consistent with the very low gradient of a shelf (Higgs, 1991). One Brushy slump-like interval has vertical fold axes and a gradational base (Figure 7), suggesting deformation *in situ*, probably due to an earthquake. Rare Brushy "slurry beds" (Zelt and Rossen, 1995) are likewise possibly seismites, formed *in situ* (cf. Higgs, 1991, 1998), consistent with a low (shelf) gradient in a tectonically active basin.

Minor Brushy facies

Two local, proximal, basal Brushy facies are:

(A) carbonate-clast conglomerates, interpreted by as debrites within "Bone submarine canyon" by Beauboeuf et al. (1999, their fig. 1.5); and

(B) thick (10s m) sandstones interpreted as contourites by Mutti (1992, plates 1a, b) and as submarine-canyon turbidites by Beauboeuf et al. (1999, fig. 1.6c).

Reinterpretation of Brushy Canyon Formation architecture

The inner Brushy, instead of deep-sea slope muds containing slope channels (e.g., Beauboeuf et al., 1999), is reinterpreted here as stacked delta-slope clinothems (foreset dip < 0.5°, undetected at outcrop), each < 15 m thick, formed by progradation during successive lake highstands (glacioeustatic; see below), separated by cryptic sequence boundaries (presumed ravinement surfaces, overlain by dark condensed sections; see above and cover photo). Delta-plain facies, presumably including paleosoils, were completely eroded by transgressive ravinement. The supposed slope channels are reinterpreted as delta distributaries, overdeepened (incised) by hyperpycnal erosion during lake-level fall and lowstand. Each distributary is inferred to pass downflow into a delta-slope erosional gully. Hyperpyncal flows were frequent and sustained during fall- and lowstand, not only because flooding rivers, increasingly incised (confined) with time, were less able to decelerate by overbanking, hence suspended-sand content was high (Higgs, 2010a), but also because the lake became progressively fresher (favoring hyperpycnicity) as fall progressed. Flows exiting the distributary accelerated (due to increase in gradient onto delta slope), producing a knickpoint that retreated erosively. Thus distributaries became long (km-10s km?), funnel-shaped inlets (non-estuarine; no evidence for tides reported in Brushy; see below). Each distributary and its terminal gully became filled, during the next rise, by sandy hyperpycnites (some influenced by waves) and muddy hypo-/mesopycnites. This concept of hyperpycnite-filled incised valleys, in contrast to the familiar estuary model, is new (Higgs, 2014a).

The outer Brushy, instead of deep-sea fans with suprafan channels (e.g., Beauboeuf et al., 1999; Gardner et al., 2003), is interpreted here as gully-fed, shelfal lowstand sand bodies (0.5-10 m thick), ovoidal in plan view (point-sourced 'balloons,' perhaps up to 10s km wide, and of greater length than width), comprising amalgamated and near-amalga-mated hyperpycnites (some wave-influenced), separated by sheet-like intervals of highstand heterolith (mud with hyperpycnites < 30 cm thick, some wave-influenced). The flat-floored, amalgamated minichannels described above, of unknown flow-transverse width, are inferred here to become progressively wider and shallower (eventually disappearing) away from the feeder gully mouth, perhaps reaching 5-10 km width, and forming a transition zone between the gully and the sand balloon that it supplies.

Outer-Brushy incised channels, previously interpreted as genetically related components of Brushy deep-sea fans ("Build-Cut-Fill-Spill" model of Gardner and Borer, 2000), are reinterpreted here as hyperpycnally filled, shelf-indenting submarine-canyon heads and their tributaries.

These new interpretations explain why the inner- and outer Brushy 'interweave' (cf. fig. 4 of Beauboeuf et al., 1999), rather than the inner downlapping the outer (see above). Interweaving is attributable to reciprocal sedimentation reflecting glacioeustatically driven lake-level fluctuations. After each rise, inner-Brushy delta progadation occurred throughout the highstand. The next fall caused lake salinity to decrease, eventually reaching a threshold level whereupon most sediment bypassed the delta front hyperpycnally (halting progradation) and was delivered directly to the shelf. This model also explains the distinctive cyclicity of the Brushy and other external flysch formations (see below).

Other flysch formations include, or adjoin, a muddy interval analogous to the Brushy's inboard muddy belt: The Bideford Formation adjoining the coeval Bude (Higgs, 1991, 2004); the Gull Island Formation directly above the Ross (Higgs, 2004); Skoorsteenberg "Unit 5" (Wild et al., 2005); Laingsburg "Units B to F" (Flint et al., 2007); and the Tres Pasos overlying the Cerro Toro (interpreted respectively as molasse and flysch by Cecioni, 1957; see also Higgs, 2015b).

Brushy Canyon cyclicity

Characteristic "packaging" (Beauboeuf et al., 1999, p. 5.1) in the Brushy, in the form of alternating amalgamated and non-amalgamated "packets" differing sharply in average event-bed thickness, is interpretable as cyclicity reflecting glacioeustatically driven lake-level rises and falls of short duration (c.1-2 ka solar cycles, superimposed on Milankovitch orbital cycles) and great rapidity (c. 2 cm/year; cf. Pleistocene) and low amplitude (2-20 m?) (Higgs, 2014a). During the lowest lowstands (thickest amalgamated packets), eustatic sea level was below Lake Brushy's spill-point level, leaving the lake perched (see above) and prolonging the lowstand.

During lake high- and lowstands alike, shelf shallowing (by deposition of hyperpycnites and background mud) was limited by storm-wave erosion (mud-draped scours; planar bases of HCS beds on mud) that maintained an equilibrium profile, intrinsic to shelves globally (Higgs 1987, 1991, 2004, 2010b), except open-ocean-facing shelves exposed by extreme eustatic falls like those of Quaternary time. This storm-shaving mechanism, in combination with the lake sill curtailing eustatically-driven lake-level falls, allowed the substantial Brushy column (c. 300 m) to accumulate entirely within a narrow, shelfal, water-depth window, without ever being exposed subaerially.

Lack of evidence for tides

The Brushy lacks reported evidence for tides, such as:

(A) dune-scale foresets (cm-m tall), with or without slack-water mud drapes;
(B) opposed ripple- or dune foresets ('herringbone'); or
(C) thin-bedded (mm-cm) heterolith with compound rhythmicity (daily, two-weekly, etc.).

This is consistent with the nannotidal character (tidal range 0-10 cm) of even the largest modern lakes, reflecting their low mass (minimal lunar attraction). Lake Brushy tidal effects would probably have been greatest at highstand, when an ocean connection existed across the sill.

Role of caves in Brushy sediment supply

If the climate was indeed humid (see above), the lack of reported macroscopic (cm size or larger) plant fragments in the Brushy requires explanation. One possibility is that sediment-supplying rivers traversed the exposed, formerly inner-ramp carbon-ates (lower San Andres Formation) inside caves, preventing local

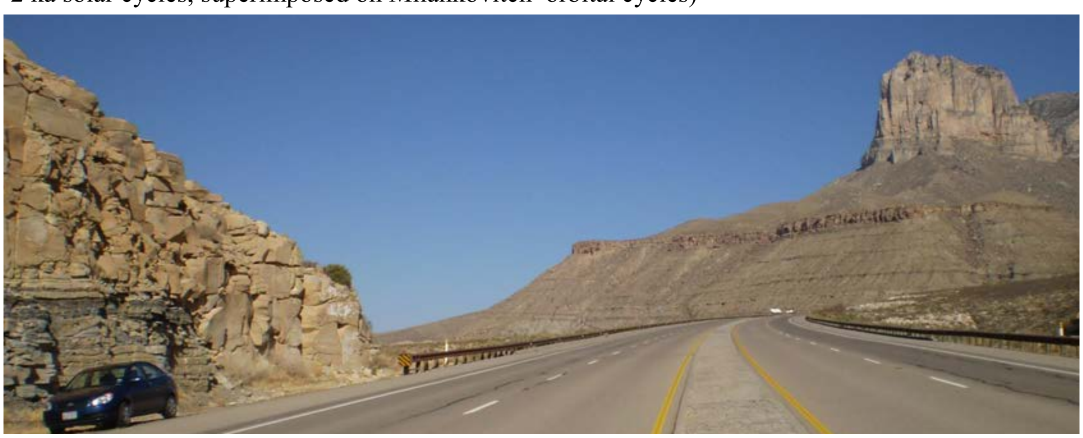

Figure 5. View northward from Stop II-3 of Scholle (2000). In the background is El Capitan peak, made of Capitan Formation carbonate. Below, both the inner (in the background) and outer (left foreground) facies associations of the turbiditic Brushy Canyon Formation are visible, viewed looking obliquely up-paleoflow. The interval below El Capitan, up to and including the ledge-forming incised channel, exposes inner-Brushy mudstone (very silty) containing sandstone channels. The dark bands are organic-rich condensed sections (Sageman et al., 1998), whose evident non-parallelism has been ascribed to draping of channel floors (Harms, 1974) or of slump scars (Zelt and Rossen, 1995; Beauboeuf et al., 1999), but may instead reflect differential compaction around channels, largely obscured by scree. The roadcut (foreground) exposes representatives of the tripartite outer-Brushy facies association: a heterolithic sheet (dark silty mudstone with turbidites); an incised sand-filled channel (to rear of car); and an amalgamated-sandstone sheet (overlying the heterolith). The usual interpretation is that inner-Brushy slope channels fed outer-Brushy deep-sea fans (with fan channels). An alternative model invokes an inner Brushy stack of delta-slope muddy clinothems, each less than 15 m thick, containing incised distributaries (filled by river-fed turbidites, i.e., hyperpycnites) that supplied outer-Brushy hyperpycnites deposited as unconfined shelfal "ovoids" (point-sourced balloons) and as fillings of shelf-indenting submarine canyons. For a close-up photo of the channel behind the car, see Scholle 2000, Stop II-3, whose caption reads "submarine fan channel incised into 'overbank' sediments" … https://geoinfo.nmt.edu/staff/scholle/graphics/permphotos/103.html

Figure 6. Sandstone-filled channel at base of a sand sheet. 15 cm striped scale barely discernible, near dead center, (in red circle) resting on mudstone beside channel wall. The channel is incised in mudstone and its base touches an amalgamated sand sheet, dominating the lower-right part of the photograph, in which an undulatory mud-draped scour (recessive) is visible. The sandstone bed comprising the upper half of the channel fill, about 45 cm thick (between sutures) is shown close-up in Figure 3, photographed immediately left of this view. Brushy Canyon Formation, eastern roadcut of the two cuts at Stop II-3 of Scholle (2000), U.S. Highway 62-180, Guadalupe Mountains National Park.

vegetation from falling into the rivers, and trapping far-traveled leaves, branches and trunks in logjams at cave narrowings, where they bio-fragmented (Simon and Benfield, 2001), forming sand- and mud-size 'coffee grounds' that ultimately reached, via cave mouths, the deltas fringing Lake Brushy. Paleocaves are indeed known within (and below and above) the lower San Andres (Kosa et al., 2003 review); also "collapsed solution cavities (paleo-caverns?)" underlie proximal Brushy strata (Gardner and Sonnenfeld, 1996). Rivers are inferred here to have emerged from caves in the Bone Spring and (overlying) Victorio Peak and lower San Andres limestones (cf. figs 3 and 4 of Beauboeuf et al., 1999). Each cave may have ended at a gorge formed by cave-roof collapse. Carbonate-clast conglomerates in "Bone submarine canyon" (see above) are reinterpretable as wall-derived debrites and rockfall deposits, interbedded with hyperpycnites, occupying a ria (drowned gorge). The "contourite" sandstones may instead be cave-mouth subaqueous fans, analogous to outwash fans at the mouths of subglacial meltwater tunnels. The fusulinids and other reworked fossils in the Brushy are interpreted here as derived from limestone exposed in cave- and gorge walls. Brushy sand fineness (mainly fine and very fine) is attributable to caves (A) trapping bedload, which fell into potholes and fissures, and (B) 'choking' the peak river velocity, limiting the (suspended) grain size arriving at the lake.

Cherry Canyon and Bell Canyon formations (supra-Brushy)

The flexed pre-Brushy ramp (see above) was eventually buried by onlapping Brushy strata. The siliciclastic facies of the succeeding Cherry and Bell Canyon formations, generally considered deep marine, differ little from the Brushy (Jacka et al., 1968; Harms and Williamson, 1988), and are thus reinterpreted here as lake-shelf deposits too. Most Cherry ripples are symmetrical (King, 1948), consistent with shelf deposition. Moreover, a possible alga in the Bell, thought to have lived benthically, suggests photic water depths of less than 30 m (McMillan, 1993). Landward the Cherry and Bell interdigitate with marine carbonates of the Goat Seep and the (overlying) Capitan formations, interpretable as interfingering of lowstand, cave-fed, lake-shelf clastics and highstand, arid, marine ramp carbonates. The marine carbonates suggest that glacioeustatic highstands drowned the lake sill more deeply than during Brushy highstands, deeply enough to turn the lake into a marine gulf. Capitan "forereef" clino-forms, interpreted by Silver and Todd (1969) as genuinely depositional but steepened by differential compaction, are reinterpreted here as pure artifacts of differential compaction, reflecting the high compact-ability of Bell laminated silt (especially the organic half-couplets), dominant in the upper Bell (Harms and Williamson, 1988). Indeed, the anomalous fineness of the "forereef" sediment (Melim and Scholle, 1995) fits a ramp model better than a platform-edge "reef" (cf. Fagerstrom and Weidlich, 1999). Rudstone tongues in the Capitan "forereef", with clasts larger than 5 m and (curiously) "probably more large (> 3 m) blocks in the middle forereef than in the upper forereef" (Melim and Scholle, 1995, p. 110), may, rather than being "forereef" debrites, simply reflect collapse of caves or ria walls. A shelf origin for the Bell supports a shallow-water (largely less than 40 m) reinterpretation of the suprajacent Castile evaporites by Leslie et al. (1996). Early compaction of the Bell by only 100% (i.e., 2:1) can account for Castile accommodation, as well as the false "forereef" dip.

Global family of Brushy Formation look-alikes

The Brushy belongs to a small clan of look-alike, depauperate, "Bude-type turbidite" formations (Higgs, 2009b, 2014a) cropping out around the world, named for the Bude Formation (UK), the first of the clan to be discussed purely sedimentologically (Reading, 1963). Four other Bude-type formations are the Ross (Ireland), Jackfork (USA), Skoorsteenberg and Laingsburg (both South Africa). The likeness between the Bude and Ross formations was documented by Higgs (2004). Others have pointed out the similarity of the Skoorsteenberg to the Laingsburg, Ross and Brushy Canyon formations (Sullivan et al., 2000, 2004; Wickens and Bouma, 2000; Wild et al., 2005). I have visited the Bude, Ross, Brushy and Skoorsteenberg.

Most of the six mentioned Bude-type formations, classified by previous authors as "fine-grained turbidites" (Melvin, 1986; numerous articles in Bouma and Stone, 2000), have been interpreted as deep-marine deposits and promoted as deep-sea-turbidite reservoir analogs (see below). In contrast a lake-shelf model like that outlined above for the Brushy has been proposed for the Bude, Ross and Skoorsteenberg formations (Higgs, 1991, 2004, 2008, 2009b, c, 2010c, d). The Skoorsteenberg was previously interpreted as shallow-water deposits (Cooper and Kensley, 1984); marine fossils have never been reported (Higgs 2010d). The Jackfork was also previously interpreted as shallow-water (Bokman, 1953), shelf deposits (at least in part, with probable HCS; Tillman, 1994) of a fresh or brackish water body (Honess, 1927), consistent with extreme scarcity of marine fossils (Harlton, 1934; Miser, 1934). According to Miser and Purdue (1929, p. 133-134), regarding the Stanley and Jackfork formations, "The practical absence of marine fossils ... combined with the wide distribution and shallow-water character of the deposits, suggests that the formations are for the most part of fresh-water origin." Jackfork trace fossils have been interpreted as belonging to the deep-sea *Nereites* ichnofacies (Pauli, 1994; Shanmugam and Moiola, 1995), but of ten ichnogenera reported in the Jackfork (table 1 of Chamberlain, 1971), only three are among the twelve "type" *Nereites* ichnogenera (Seilacher, 1978). Only one of the ten, *Helminthopsis*, is common in the *Mermia* ichnofacies, thus the published assemblage (Cham-berlain, 1971) is perhaps a novel, brackish-lake ichnofauna. Intervals of coarser, locally fossiliferous, cross-stratified sandstone interpreted as submarine-fan channels by Pauli (1994) could instead be incised-valley fluvial fills (with reworked fossils) within "normal" Jackfork shelf facies. Intraformational "boulder beds" interpreted as slope deposits by Tillman (1994) might instead be pseudo-slumps (seismites) deformed essentially *in situ* on a shelf.

Two other shared attributes of the Bude-type formations listed above are:

(1) Carbo-Permian age; and
(2) All were deposited along two, intra-Pangean collisional belts of great length (> 1000 km; no modern analogs), amenable to early collision of promontories, pinching off sectors of the shrinking, intervening remnant ocean, forming large lakes (Higgs, 2010c-d), namely Lake Bude (Higgs, 1991), Lake Karoo (Higgs, 2008), Lake Brushy (Higgs, 2014b) and Lake Jackfork (proposed here).

One of the two collision belts was the long, diachronous, nonlinear belt along which Gondwana and Euramerica collided (Scotese and McKerrow, 1990, figs 17-20; Scotese, 2002; Blakey 2003, fig. 5B, and larger, color version at:
http://cpgeosystems.com/340moll.jpg),
producing Lakes Bude (including Ross Formation; Higgs, 2004), Jackfork and Brushy (from east to west), each delimited along strike by alluvial, overfilled foreland basins and/or by foreland uplifts. Broad westward younging (Late Carboniferous to Permian) among the three formations is consistent with diachronous closure of the Rheic-Phoibic Ocean (Scotese and McKerrow, 1990, figs 16-20). The other intra-Pangea collision belt was that between Gondwana and a Patagonia-Falklands terrane (Milani and de Wit, 2008, fig. 11; Ramos, 2008, fig. 12), where the Laingsburg and laterally equivalent Skoorsteenberg Formations were deposited in Lake Karoo (Higgs, 2010c-d).

A similar, long-collision-belt model can be applied to other, younger external-flysch formations, of Mesozoic and Cenozoic age, such as the Annot, Hecho, Marnoso and Cerro Toro (Higgs, 2015a, b). Unlike Bude-type formations (Paleozoic), the mudstones of these younger formations contain diverse benthic foraminiferal faunas. The forams were interpreted by Higgs (2014a) as largely reworked (in suspension) in rivers from near-coeval internal flysch exposed in the orogenic mountains along strike; regardless, they indicate that at least some of the respective ocean-lake highstands were fully marine. The lack of reported forams in Bude-type formations, other than the Brushy's fusulinids (reworked by rolling), may simply be an evolutionary effect, reflecting the paucity of pre-Mesozoic foram taxa.

Implications for Brushy exploration and development

The new Brushy lake-shelf-hyperpycnite model is crucial for exploration and development in the Brushy itself, and also in the overlying Cherry Canyon

Figure 7. Pseudo-slump interval, interpretable as a seismite, formed *in situ*. 15 cm scale near dead center (blue circle), horizontal, on top of sandstone bed immediately below deformed interval. Undeformed strata occur immediately above (top left) and below the contorted interval, indicating that deformation was syn-sedimentary. Deformation *in situ*, rather than by lateral movement (slumping), is indicated by: (1) gradational base; (2) downward decrease in fold amplitude; and (3) upright fold axes. Brushy Canyon Formation, western roadcut of the two cuts at Stop II-3 of Scholle (2000), U.S. Highway 62-180, Guadalupe Mountains National Park. See Scholle (2000) for another photograph of same interval …
https://geoinfo.nmt.edu/staff/scholle/graphics/permphotos/104.html

and Bell Canyon formations, whose silici-clastic parts had essentially the same depositional environment (Higgs, 2014b). Workers accepting the conventional deep-sea-fan model interpret sand bodies drilled in the outer Brushy-Cherry-Bell formations as suprafan channels, overbank lateral splays (behind levees) and distal lobes (e.g. Nance, 2006, and references therein), resulting in particular predictions concerning sand-body geometry, orientation and size. In contrast, in the new model, no levees or overbank splays are predicted. In the old model, interpreted fan channels are predicted to split distally and become smaller (shallower/narrower) distally, eventually disappearing (e.g., Beauboeuf et al., 1999, figs 11 and 12). Based on this model, Beauboeuf et al. (1999, fig. 12) explained the basinward decrease then increase in channel size (width/depth) they observed along the outcrop belt in terms of overlapping fans fed from different directions, an awkward solution. In the shelf model, the same channels are interpreted very differently, as the heads and tributaries of shelf-indenting submarine canyons, predicted to widen and deepen distally and to branch proximally. Tabular sand bodies interpreted as splays and lobes in the old model are, in the new model, hyperpycnite balloons. Abundant opportunities now exist for discovering new Brushy-Cherry-Bell oil- and gasfields, and extending old ones, by using the new model as a guide and predictor while reworking the enormous database. This mammoth task will include integrated facies analysis (cores, image logs), recorrelation of wireline logs, and interpretation of seismic slices. The new model will greatly influence future placement of wells (explor-ation and development; producers and injectors), positioning of perforations, reservoir flow modeling, and reserves calculations.

For effective Brushy exploration and development, further detailed outcrop studies are strongly recommended, not only in the Brushy but also in look-alike formations around the world. Particularly favorable is the Bude Formation, offering: three times greater thickness (c. 1.3 km) than the Brushy; 50 years of published sedimentological debate (sum-mary in Higgs, 1991); a 15 km Atlantic-facing cliffline with intermittent wave-cut platforms (2.5-dimensional exposure); wave-polishing of the cliff base, revealing exquisite sedimentological detail; 100% public land (contrast Brushy, Skoorsteenberg) with free access by beach and cliff path; and proximity to airports (London 3.5 hours, Bristol 2.5, Exeter 1.5).

Brushy unsuitable as an 'outcrop analog' for passive-margin deep-sea oilfields

All of the mentioned Bude-type formations (Bude, Brushy, Ross, Jackfork, Skoorsteenberg, Laingsburg) except, ironically, the Bude have been recommended in the literature as outcrop analogs for truly deep-sea-turbidite reservoirs, moreover on passive margins, including the Gulf of Mexico, western Europe (North Sea), Brazil and Africa (Beauboeuf et al., 1999; Bouma and Wickens, 1991; Chapin et al., 1994; Coleman et al., 2000; Martinsen et al., 2000; Slatt et al., 1997, 2000; Sullivan et al., 2000, 2004; Wickens and Bouma, 2000; Lien et al., 2003; Hodgetts et al. 2004; Larue, 2004; Fugelli and Olsen 2005; Bouma and Delery, 2007; Bouma et al., 2007a-d; Chapin and Tiller, 2007; Goyeneche et al., 2007; Hodgson et al., 2007; Shew, 2007a, b; Pyles, 2007a, b, 2008). The dangers of this practice have been clear since the warning by (Mutti et al., 2003, p. 751-752) that "turbidite sedimentation of divergent continental margins differs dramatically from that recorded by ancient foredeep basins." Use of improper analogs risks billions of dollars (see above). Obvious contrasts between passive-margin deep-sea turbidite environments (fans, slope channels, slope minibasins) and the envisaged Bude-type hyperpycnitic lake shelves (no modern analog) that must cause great differences in sand distribution, geometries, architectures and granulometry include:

(1) Active versus passive tectonic setting, e.g., foreland basins have nearby highlands, affecting sediment volume and caliber, and are prone to strong earthquakes (hence injectites, seismites);
(2) Unlike deep-sea-fan channels, lake-shelf channels (shelf-indenting canyons) are entirely incisional, lack levees, have low sinuousity, deepen downflow, and bifurcate upflow instead of down, thus intra- and extra-channel sand distribution and geometries must differ greatly;
(3) Deep-sea fan channels feed overbanks splays and terminal lobes, whereas the inferred lake-shelf canyon heads and tributaries do not;
(4) Bude-type premature amalgamation due to low salinity is inapplicable in the sea;
(5) Slump-generated turbidity currents are more likely on continental slopes (tall, favoring ignition), while hyperpycnal turbidity currents are less favored (normal marine salinity). Slump-induced turbidity currents are certain to differ significantly from hyperpycnal flows in duration and velocity, hence runout distance, competence, capacity and susceptibility to Coriolis deflection. These factors again affect predictions of sand distribution, geometries, dimensions, granulometry and matrix content (affecting porosity-permeability). Thus, deep-sea-fan lobes are likely to differ substantially from lake-shelf hyperpycnite balloons in properties like length, volume, grain-size distribution and interconnectedness; and
(6) mass transport deposits are voluminous on continental slopes.

Significantly, typical flow rates from Brushy, Cherry and Bell oil wells and Jackfork gas wells (10s-100s BOPD; 1-5 MMcf/d, e.g., Montgomery, 1996; Montgomery et al., 1999, 2000) are 1-2 orders of magnitude less than from deep-sea reservoirs under present-day passive margins (though allowance must be made for contrasting drilling depths and pressure regimes). This difference can be largely attributed to Bude-type turbidites' relatively fine grain size and (therefore) high matrix content. During deposition of a turbidite, clay injected into the aggrading sand bed by turbulent-eddy downstrokes (Dade et al., 1991) is retained between settled sand grains by a filtering effect, whose effectiveness increases with decreasing sand size (Fries and Trowbridge, 2003), hence finer sand beds have higher matrix content. This injection-and-sieving model solves the long-standing controversy over the origin of mud matrix in turbidites globally, and negates the general opinion that most matrix is secondary (e.g., Pettijohn et al., 1987, p. 174).

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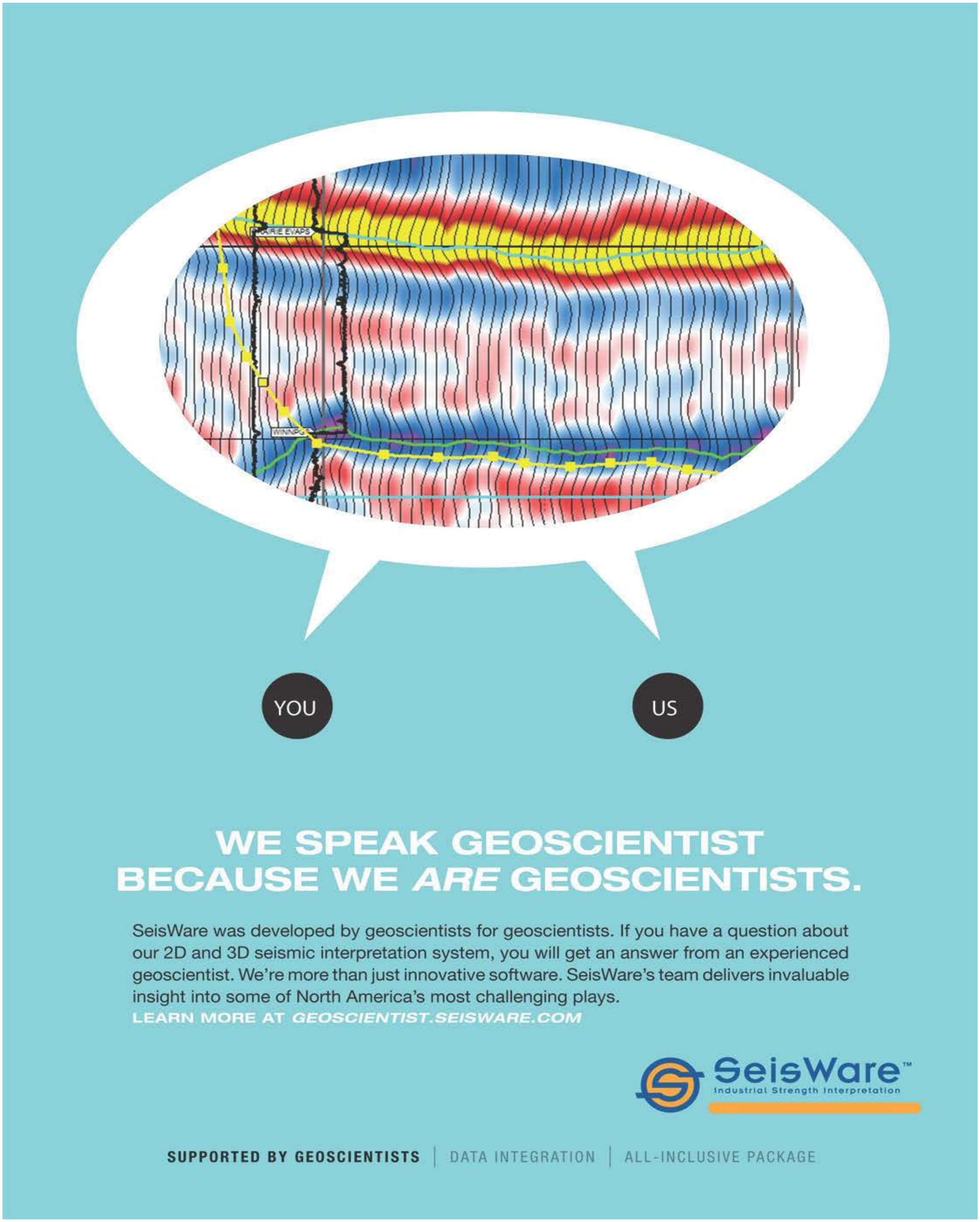
Sixteenth Annual
Abilene Geological Society
Desk and Derrick Club of Abilene
Golf Tournament

18 Hole – Four Person Scramble Format
Tuesday, **May 12, 2015**
Shotgun Start: 1:00 p.m.
Diamondback Golf Club – Abilene, Texas
$80.00 per person
Entry fee includes lunch, green fees, golf cart, non-alcoholic beverages and range balls.
Hole-In-One prizes on all par 3 holes
Closest-to-the-pin and longest drive prizes on designated holes
Door Prizes

For registration information contact:
David Morris 325-677-9121
Or
Go To the AGS Website at:
www.abilenegeo.org
to print registration form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West Texas Geological Society Spring Fling

WTGS members and their guests are invited to join us for this year's WTGS Spring Social co-sponsored by Riley Geological Consultants. If you know someone who is not a member of WTGS and should be, please invite them to this event where they can meet other WTGS members and see what they have been missing.

It will be held on **Friday, May 15th** at the Riley Geological Consultants office
at 2913 West Industrial, Midland, TX.
There will be plenty of food, beer and wine along with live music.
The fun starts at **6:00 pm** and goes until **9:00pm**.
Dress is casual, so come as you are. We hope to see you there. There is no charge for this event.

AAPG House of Delegates to Consider Bylaw Changes

Mike Raines, WTGS Delegate Chairman

AAPG's House of Delegates (HoD) has announced five proposed amendments to AAPG's Bylaws, which will be considered at the May 31, 2015 Annual Meeting in Denver. A summary is provided below, but to see the exact wording of the proposed changes, please visit AAPG's HoD webpage: (http://www.aapg.org/about/aapg/leadership/house-of-delegates-hod/bylaws-proposals). **Please think about these proposed changes and let one of WTGS's Alternates or Delegates know what you think!** Our job is two-fold: 1) represent the opinions of WTGS members to AAPG through the HoD; and 2) make sure WTGS members are aware of proposed changes to the structure of AAPG so that your opinions can be as informed as possible. It is true that sometimes new information comes out during the meeting itself which may change our position as individual delegates, however, our primary objective is to represent you! That means we need to hear from you.

The first item deals with the elected position of Editor. This proposal would: a) eliminate the requirement for two candidates on the ballot; b) move up the start time of the Editor; c) limit the Advisory Council's power to select Editor candidates by requiring the Advisory Council to select from a list provided by the editorial board; and d) change the procedure used to fill a vacancy in this position. *(Note: currently the position is filled by the candidate who did not win the election. The new method would be that the editorial board would select a candidate, provide the name to the Advisory Council and that candidate would be voted on by the Executive Committee.)*

The second amendment moves the dates of elections (and related deadlines) from the current early summer cycle to a mid-winter cycle.

The third proposal provides a narrower limitation on nominations, honors and awards. With the current wording, past presidents are included in the restricted group for 3 years after expiration of their term. The new wording would allow past presidents to be nominated for office or selected for honors or awards by the Executive Committee.

The fourth amendment would change the names of international regions. Canadian Region, for example, would change to Canada Region, African Region would change to Africa Region, etc…

The final amendment would provide a method for the Executive Committee to establish (and dissolve) Technical Interest Groups and Special Interest Groups.

2015 WTGS Delegates and Alternates to AAPG HoD:

David J. Entzminger	entzminger@whiting.com	(432) 686-6741
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R. Tom Dickey	tdickey@jdmii.com	(432) 686-2063
S. Mike Burke	mburke@concho.com	(432) 818-2399
Toby Carleton	tobycarleton@tocor-inv.com	(432) 685-1209
Will Green	wgreen@midland.edu	(432) 685-0103

PBS-SEPM & WTGS Luncheon Meeting

SPECIAL GUEST: ALTON BROWN

Midland Center, Midland, Texas 11:30am, May 28th, 2015

Geology of the Pyramids of ancient Egypt

The pyramids of ancient Egypt demonstrate the sophisticated engineering skills of ancient civilizations. The way the pyramids were built and their location is influenced by the local and regional geology. This will be illustrated by a discussion of the geology at Saqqara, Meidum, Dahshur and Giza in relation to design of their pyramids.

Pyramid design arose over about a hundred year period from the step pyramid of Djoser to the much larger, great pyramid of Khufu at Giza. Two trends are evident: increasing size and increasing size of stone blocks comprising the pyramids. These trends actually reflect in part the geology of the building sites. With time, site selection became increasingly sophisticated such that the geology of the site became perhaps as important as the spiritual significance of the site.

The great pyramid of Khufu sits on the Giza plateau. This site has in general both excellent foundation and abundant, thick bedded limestone suitable for large building blocks. The Giza plateau is a karsted surface truncating Eocene strata dipping south and southeast at about 8 degrees. Exposed bedrock therefore changes across the site. The pyramids stand on a hard nummulitic limestone whereas the sphinx was carved from a softer bedded wackestone. The sphinx shows much greater erosion than other nearby areas due to its weaker bedrock. Greater erosion has been interpreted (erroneously) by some as evidence for the sphinx being much older than the pyramids. However, simple superposition relationships between various monuments demonstrate the contemporaneity of the Sphinx and the pyramids.

Most of the pyramid volume is composed of local nummulitic limestone. Casing stone and minor amounts of interior stone are imported to the site using the Nile River. The great size of the pyramids present significant engineering challenges. The biggest challenge was time. Pyramids had to be built within the pharaoh's lifetime. This would require shifting about 6 one ton+ blocks per minute during the building season for on-time completion of the great pyramid, for example. Only the most primitive tools and manual labor were available to meet this goal. Various construction short cuts have been proposed over the last few years. We will use photographic evidence from the site to help constrain the various proposed building shortcuts.

The Awards Dinner for
The West Texas Geological Society
will be held on Thursday, May 21, 2015
at the Petroleum Club of Midland.

WTGS requests your presence to help us
honor the work of our distinguished colleagues.

Cocktails 6:00pm Cash Bar — *RSVP by May 19, 2015*

Dinner 6:45pm

$40.00 per person — *432. 683.1573 or wtgs@wtgs.org*

PERMIAN BASIN SECTION SEPM

YOUNG PROFESSIONAL AND INTERN FIELD TRIP

June 11-14, 2015

Registration Form

- Four day multi-disciplined field trip in the Guadalupe Mountains for geology, engineering and land young professionals and interns
- Trip led by Dr. Emily Stoudt and Dr. Robert Trentham from The University of Texas of the Permian Basin, who have a combined 60 years of geological experience in research, development and production in the Permian Basin. They will be assisted by Dr. Cory Hoffman of SM Energy.
- Robert Campbell (engineering), Chris Fling (land),Teri McGuigan (land), and Blake Pitcock (land) will -- provide mentoring support and have comparable years of Permian Basin experience in their respective professions.
- Goal is to educate participants in combining outcrop data with industry exploration and production techniques in a multi-disciplined environment
- Participants will have opportunity to observe world-class outcrops of shelf to basin deposits that are direct analogues to producing fields in the Permian Basin
- Lectures covering geology of west Texas, carbonates, sequence stratigraphy, quick and simple log and engineering calculations and land practices
- Classroom exercises on general land practices, sequence stratigraphy, log correlation, water saturation determination, seismic interpretation and production analysis
- Break out sessions specific to each discipline

Participants will leave Midland, TX on June 11, travel to Carlsbad, NM, where they will stay at the Stevens Inn, and return to Midland, TX, the evening of June 14. Included in the costs: round trip transportation from Midland, three nights lodging, three breakfasts, three lunches, refreshments in the field, guidebook and handouts.

Limited space is available, so the first to register will be given priority.

Cost per person for Double Occupancy is $1000.00
(Single rooms will be allocated based on availability and happenstance of an odd number of male or female participants)

Discipline (Mark One) **Geologist ( )** **Land Professional ( )** **Engineer ( )**

REGISTRATION FEE NON-REFUNDABLE AFTER June 3, 2015

Name: ______________________________
Company/Affiliation: ______________________________
Mailing Address: ______________________________
Business Telephone: ______________ Fax Telephone: ______________
Email address: ______________ Roommate: ______________
Rooms are nonsmoking Special Dietary Needs: ______________

Payment check, cash or credit card:
( ) I authorize you to charge the above to my:
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Card Number: ______________ Signature: ______________

Make checks payable to PBS-SEPM.
Registration information and payment to: PBS-SEPM P.O. Box 1595, Midland, TX 79702
Credit card orders may be faxed to (432) 686-7827
For additional information contact: PBS-SEPM Office (432) 683-1573 or Robert Campbell (432) 557-2458

CALENDAR

May 2015

S	M	T	W	TH	F	S
					1	2
3	4	5	6	7	8	9
10	11	**12**	13	14	**15**	16
17	18	**19**	**20**	**21**	22	23
24	25	26	27	**28**	29	30
31						

WTGS Luncheon
Midland Center
11:30 am, $15.00

PBS-SEPM Luncheon
Midland Center
11:30 am, $15.00

WTGS Awards Dinner
Petroleum Club of Midland
6:00 pm, $40.00

SIPES
Midland Country Club
11:15 am

PBS-SEPM YP & Intern Field Trip

WTGS Spring Fling
2913 West Industrial,
Midland, TX.

WTGS - **12 - Stephen A. Sonnenberg -** *"Petroleum Geology of the Niobrara Formation, Silo Field, Wyoming"*

WTGS Spring Fling - **15 -** @ Riley Geological Consultants office at 2913 West Industrial, Midland, TX.

PBS-SEPM - 19 - David A. Ferrill - *"Mechanical Stratigraphy and Normal Faulting"*

SIPES - **20 - Harry Holzman Jr -** *"Iraq Oil Potential"*

WTGS Awards Dinner - **@ Petroleum Club of Midland,** Cocktails - 6:00 pm, Dinner- 6:45 pm $40.00 per person (must RSVP by May 19th)

PBS-SEPM/WTGS - 28 - Alton Brown - *"Geology of the Pyramids of ancient Egypt" @ The Midland Center, 11:15 am -1:00, $15.00*

Please remember to make reservations for the WTGS/PBS-SEPM Luncheons: call (432) 683-1573, e-mail wtgs@wtgs.org, or visit www.wtgs.org

OF EVENTS

June 2015

WTGS Luncheon
Midland Center
11:30 am, $15.00

PBS-SEPM Luncheon
Midland Center
11:30 am, $15.00

SIPES
Midland Country Club
11:15 am

PBS-SEPM YP & Intern Field Trip

S	M	T	W	TH	F	S
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7	8	**9**	10	**11**	**12**	**13**
14	15	16	**17**	18	19	20
21	22	23	24	25	26	27
28	29	30				

WTGS - 9 - David M. Petty - "Mineralogy and Petrology Controls on Hydrocarbon Saturation in the Three Forks Reservoir, North Dakota"

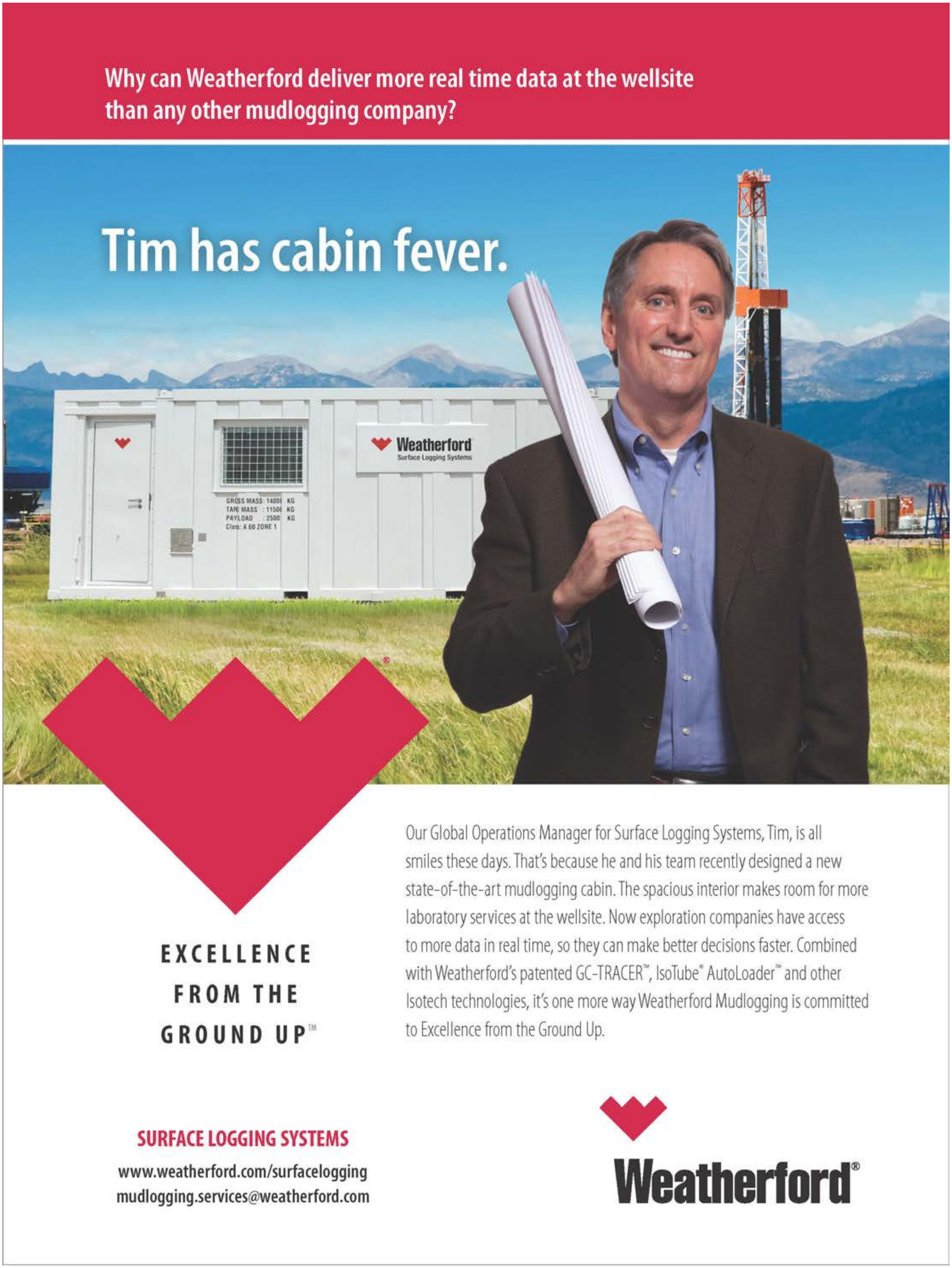
PBS-SEPM YP & Intern Field Trip - 11-14 Please call the WTGS office for more information 432-683-1573

SIPES - 17 - Valentina Vallega - "Borehole Images: From Acquisition to Applications"

Articles Needed!

If you would like to submit an article for the WTGS bulletin please email it to wtgs@wtgs.org

Please remember to make reservations for the WTGS/PBS-SEPM Luncheon: call (432) 683-1573, e-mail wtgs@wtgs.org, or visit www.wtgs.org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PBS - SEPM

Luncheon

David A. Ferrill

Tuesday, May 19th, 2015

Midland Center - Corner of Wall and Main, downtown Midland
Lunch : 11:30 AM **Cost** : $15
Make Reservations with Paula Sanchez
(432-683-1573)

Mechanical Stratigraphy and Normal Faulting

David A. Ferrill, Alan P. Morris, Kevin J. Smart, Ronald N. McGinnis

"Mechanical Stratigraphy and Normal Faulting"

Abstract:

Analyses of normal faults at displacements spanning 7 orders of magnitude (mm to km) inmechanically layered strata reveal that mechanical properties of rock layers strongly influencenucleation points, failure mode (shear versus hybrid), geometry (e.g., refraction through mechanical layers), rate of propagation with respect to displacement (and potential for fault tip folding),displacement partitioning (e.g., synthetic dip, synthetic faulting, fault core displacement), fault core and damage zone width, and fault zone deformation processes.

In layered carbonate and shale strata, faults nucleate first in more competent limestone ordolostone beds and with steeper dips than fault segments in more argillaceous carbonate or shalelayers. Consequently, faults commonly refract through mechanically layered strata, defined by steep hybrid or shear failure segments in competent layers, and more gently dipping shear failure segments in less competent strata. Slip along more gently dipping segments results in dilation of steep faultsegments, even at depths of several kilometers. Systems of steeply dipping normal faults in brittle competent units may drive displacement into less competent strata where displacement is accommodated by distributed shear or slip on a system of low angle faults. With increasing extensionand displacement, this may develop into an imbricate normal fault system, and a series of low anglefaults may link to form a through-going detachment. Whereas slip initiation on a low angle normal fault is mechanically unlikely, driving of slip from high-angle faults in competent mechanical layers into anincompetent layer is mechanically viable, and can explain geometries of small scale systems observed in the field and seismic reflection data, as well as enigmatic earthquake patterns.

Fault propagation may slow or cease in incompetent units such as clay or evaporite-rich layers. Continued displacement on a fault with an arrested tip leads to folding beyond the fault tip, producing a fault tip monocline or fault propagation fold. Such folds are therefore the result of arrested or delayed fault propagation. With continued displacement, the fault may break through the monocline and leave tilted layers with dip in the same direction as the fault (i.e., synthetic dip) in the hanging wall, footwall, or both fault blocks. While this synthetic dip is often described as fault drag, we conclude that it is theproduct of folding prior to fault break-through and not the result of frictional drag on the fault.

The width of the faulted monocline is a primary control on fault zone (or damage zone) width,and is determined at the onset of folding related to the mechanical stratigraphy rather than a simple function of fault displacement. The other primary determinant of fault zone width is the spacing between overlapping fault segments (or width of relay ramps) that cooperate to define a fault zone.This spacing develops early and the displacement tends to localize into a narrower zone with increasing displacement, straightening and smoothing the fault surface by severing asperities that are poorly oriented for slip in the ambient stress field. The width of the segmented fault array is established early, and therefore this control on damage zone width is also not directly related to fault displacement.

Analog modeling shows that fault systems develop in displacement versus length space along a stairstep path rather than a linear self

Continued on page 37


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-similar path, due to periodic jumps in fault length when fault segments link. With increasing displacement, fault zones with increasingly wide separation begin to cooperate and link. Thus fault zone width also grows along a stair-step trajectory with respect to displacement, the widening steps again associated with cooperation and linkage.

Similar to fault refraction described in carbonate rich strata, fault refraction is also seen infaulted volcanic strata of different competence. Where unconsolidated or poorly consolidated material overlies dilational fault segments in competent layers near the ground surface, drainage of material downward into the resulting voids along dilational fault segments leads to formation of pit craters and troughs, and incorporates externally sourced material into the fault zone. Faulting in volcanic rocks atthe ground surface in some cases also shows evidence of fault tip folding, fissuring due to outer-arc extension (bending strain), and reactivation of cooling joints to define irregular largely dilational fault zones that experience toppling failure at the ground surface. Young and active fault zones developing at the surface in jointed volcanic rocks may appear to be degraded fault scarps, when in fact this is the character of the faulting process associated with upward fault propagation, fault tip folding, dilation of cooling joints to accommodate bending strain in the outer arc(s) of the monoclinal fold, and blocktoppling and sliding.

These detailed investigations are progressively dispelling some myths about normal faulting, for example: (i) planar fault shape in dip profile, (ii) imbricate normal fault initiation due to sliding on low angle detachments, (iii) the concept of frictional fault drag, (iv) self-similar development of displacement to length ratios, (v) self-similar fault zone widening as a direct function of fault displacement, and (vi)that faults are not dilational features or important sources of permeability (e.g., in unconventional reservoirs).

Speaker:

David Ferrill received his B.S. degree in geology from Georgia State University in 1984, his M.S. degree in geology from West Virginia University in 1987, and his Ph.D. in geology from the University of Alabama in 1991. He is a licensed professional geoscientist (geology) in the state of Texas. Before joining Southwest Research Institute in 1993, he was an exploration geologist at Shell Offshore Incorporated. David is now a director at Southwest Research Institute and performs geologic analyses, structural geologic consulting, and training for the oil and gas industry. To contact David please address letters to the following address:

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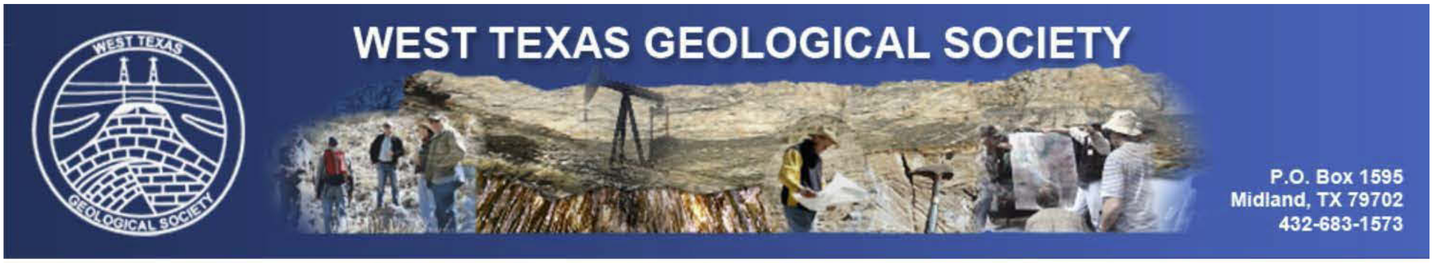

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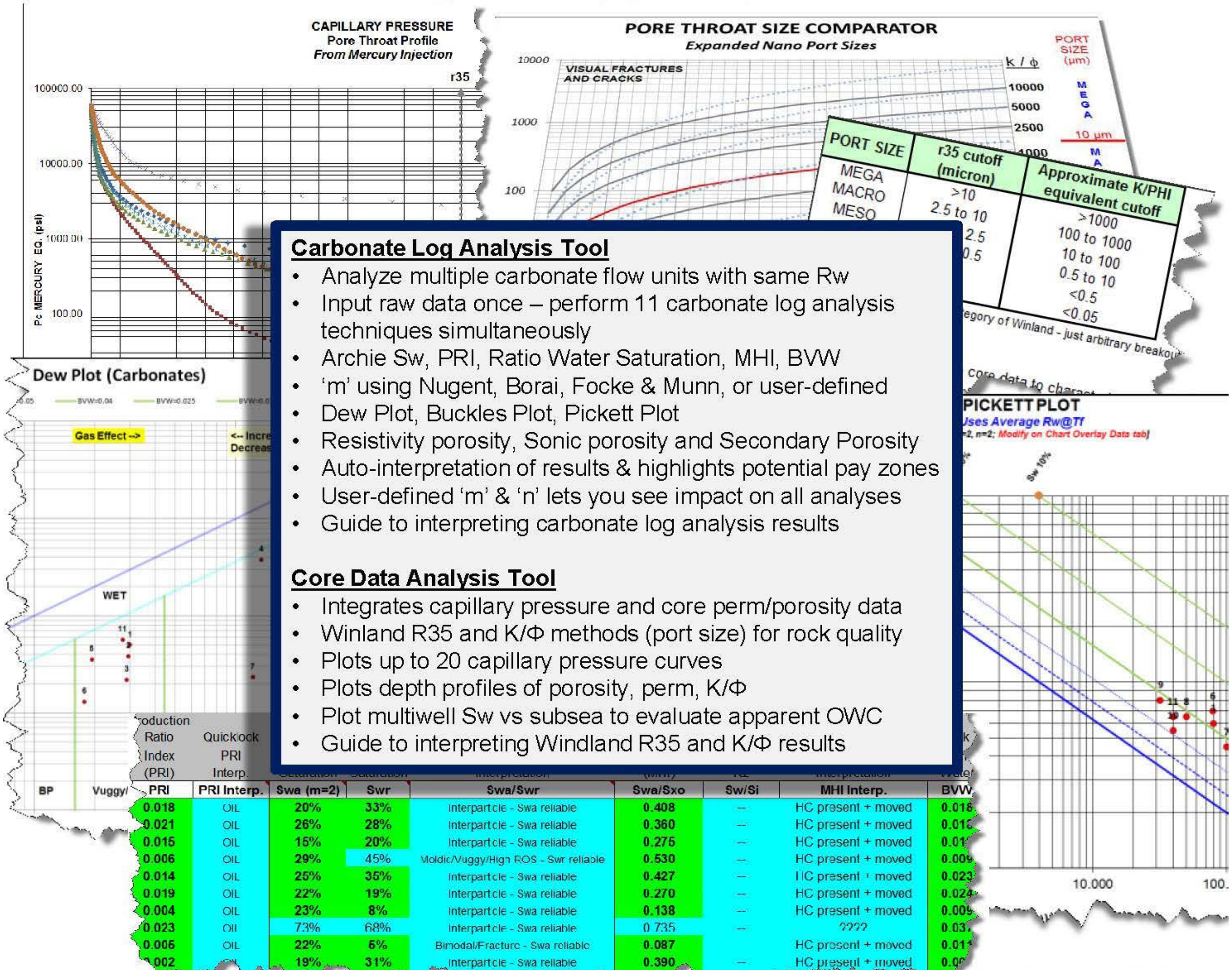

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Mineralogy, Petrology and Hydrocarbon Saturation in the Three Forks Reservoir, North Dakota

David M. Petty

The Three Forks reservoir forms the lower part of the "Bakken pool" in the North Dakota portion of the Williston basin. The upper portion of the Three Forks Formation (1st and 2nd Benches) consist dominantly of dolomite, with secondary amounts of quartz or feldspar sand and silt grains, and variable amounts of clay minerals (mostly illite). Anhydritic and calcareous beds occur in the lower half of the formation (3rdand 4th Benches).

In most oil-productive areas of western North Dakota, three reservoir rock types can be defined in the 1stBench based on mineralogy, capillary pressure characteristics and water saturation distributions. The best Three Forks hydrocarbon saturations occur in brown to brownish-orange to tan, sandy to silty, clay-poor dolostone. Within the oil column, this end-member lithology typically has 2-7% porosity (4.3% average) and 5-40% water saturation. The average mineral content is 63% dolomite, 31% quartz-feldspar and 3% illite (values less than 1% not listed). A second end-member rock type is green, silty, dolomitic mudstone that typically has 5-11% porosity (8.9% average) and 40-90% water saturation. The average mineral content is 35% dolomite, 31% quartz-feldspar, 30% clay minerals (23% illite, 4% chlorite, 3% illite-smectite), and 2% pyrite-marcasite. The third rock type consists of mixed brown and green, sandy to silty dolostone, with intermediate reservoir rock properties. It includes laminated and brecciated lithologies.

Below the 1st Bench, several reservoir rock types occur; however, the brown, clay-poor sandy-silty dolostone lithology is the main oil-bearing rock type in all portions of the Three Forks. The brown dolostone rock type is common in lamina, uniform beds and breccia beds that are interbedded with clay-rich dolostone. The thickest brown dolostone unit, informally referred to as the "Basal Clean" portion of the 1st Bench, is typically 2-3 meters thick, consists of 60-90% brown dolostone and can be correlated regionally. It is the horizontal drilling target in many areas. Porosity occurs in intercrystal spaces between planar-s dolomite crystals. Permeability (Ka) is typically between 0.001 and 0.01 md in the central portion of the oil-producing area. Porosity and permeability increase gradually updip into shallow, water-bearing areas.

Due to small pore-throat sizes, oil column heights greater than 3,000 feet would have been needed to achieve observed hydrocarbon saturations in a water-wet system. Under these conditions, the oil column is too thin to be explained by simple buoyancy-driven oil emplacement. Based on an analogy with very low permeability, continuous gas reservoirs, it is inferred that overpressure (current or ancient) that developed during maturation of overlying Bakken shales was required to emplace oil in rocks with existing low permeability. The brown dolostone rock type is a reservoir in basinal areas with overpressure, but it acts as a baffle or seal in normal-pressured flank areas. On a regional scale, hydrocarbon migration was primarily vertical; oil was forced downward under pressure from overlying Bakken shales and there was limited oil migration outside of overpressure areas or areas with regional fracture conduits.

Speaker: David M. Petty

David Petty has 36 years of industry experience working as a petroleum geologist in the Williston basin, Permian basin, Michigan basin, Tunisia and Egypt. He received a B.S. degree in Geology from Texas A&M University in 1976 and a M.S. degree in Geology from New Mexico Tech in 1979. He has worked for Tenneco Oil Company (1979-1989), British Gas (1989-1994), American Exploration (1994-1996), Belco Energy (1996-2001), Westport Oil & Gas (2001-2004), Kerr-McGee Corporation (2004-2006), Anadarko Petroleum (2006), and Hess Corporation (2006-present). Most of his work experience has been in the North Dakota and Montana portions of the Williston basin, and most of his research investigated the stratigraphy, diagenesis and reservoir rock properties of early to middle Paleozoic strata in the Williston basin and surrounding outcrop areas. Since 2006 he has worked both Bakken and non-Bakken North Dakota assets for Hess Corporation.

Jesse's

Jesse G. White

Jaunts

China Part 3

In the previous article on China I left you in Anqing. I had just finished lunch with Qian's relatives and we were heading for Taihu in a taxicab. The green and white cab was small and smelled like a men's locker room and Chinese takeout. I was crammed into the front seat like a pickled pig's foot in a jar with luggage on my lap. Qian, Wei, and Xinping also had bags in their laps and were smashed in the back like crumpled newspapers. Two of them were sleeping, heads back, and mouths open the other staring out the window.

Anthracite pile at Pu Chu School in Taihu, China

The windshield was dusty and smattered with bug juice. The four side windows were down. The sky was a dusty tan-blue, the temperature stifling hot, and the air was humid and stuck to my skin like melting duct tape. The wind rippled into the car like a hot wet chamois. My shirt was drenched and salty dirty beads of sweat dripped off my brow burning my eyes and obscuring the already hazy welkin. It took more than an hour for us to get to Taihu from Anqing. I didn't fall sleep. I just wiped my brow on occasion and watched the scenery drift past in blurry watercolor streaks like a pleasant day gazing through a rain dotted window pane.

We drove by the massive Anhui Huaining Hailuo cement plant and through the forested Yichuan-Daye foreland fold belt in the Yangtze block northwest of Anhui on G318. The cement plant is easily the size of the Midlothian, Texas plants or maybe even larger. We turned on to G50 near Qianshan. Qianshan is the gateway to the Tianzhushan National Geopark. G50, also known as the Shanghai-Chongqing Expressway or Huyu Expressway, is a major thoroughfare. For nearly the entire stretch from G318 to Taihu the median is carefully manicured shrubbery and small trees. It is amazing the amount of work it must take to keep it looking as cut and polished as it does. We turned off on S211 to Taihu in the late afternoon.

One of the first things I saw in Taihu was the monolithic concrete statue of the mythical giant Pangu. He is bearded with shoulder length flowing hair and bursting out of a mountain with a hand axe. According to Chinese mythology the story of Pangu is roughly as follows:

The infant universe was an amorphous chaos that consolidated into a cosmic egg. Within this egg, the Yin and Yang were perfectly balanced and from this purity, Pangu burst forth. He then created the world by separating the Yin and Yang using his giant axe. This action formed the earth and the sky. For millions of years Pangu held the earth and sky apart and as they grew, he grew. When he died, as all things must die, his cosmic body turned into the stars, sun and moon, mountains, fertile land, forests, wind, thunder and rain, precious minerals, and the animals.

We arrived at Jixin and Ruiying's home (Qian's parents). They live in a small concrete bungalow inside the protected grounds of a local school. Men dressed in light blue uniforms with dark blue collars, pockets, and stiff brimmed caps guarded the main gate. We drove past an oval dirt running track and parked in front of a group of narrow and elongate concrete living quarters. Each row was separated by small gardens and a sidewalk that led to individual ground floor doors. The structures were cracked and partially crumbling which gave them a certain charm. Chinese flags flew atop every building and photovoltaic solar panels adorned every roof.

There was a large group of kids hanging out in front of the oval track on the concrete bleachers. They saw me exit the car and started whispering, laughing, waving, and yelling, "Nihao! Nihao! Hello! Are you American?" We walked down a long sidewalk passing bungalow entrances until we reached the end of the sidewalk and a small tree. Just before the tree was the open door that was Jixin and Ruiying's home. Above the door hung a small red banner with shiny gold Chinese characters that read, "Good luck in the year of the horse".

Immediately inside the entrance is the cozy red tiled dining room. Off to the left is the kitchen. It has red tile floors, white tile walls and counters, and cupboard doors made of plywood. There is a small sink, a two burner electric cooktop, and on the counter sat a small cutting board, knife, and a sliced Persian cucumber. Through the dining room is the exit into the courtyard. It contains small vegetable gardens, a raised concrete fish pond, an empty chicken coop, a few trees, and clotheslines hanging between the buildings. Neighboring the kitchen is the bathroom and shower. Further down is the wood fired cooking stove and further still another storage room. Opposite and across the courtyard is a two story building including living room and bedrooms.

I was awakened later that day from a short nap by Qian's second cousin Zhuang Zhuang who was only three years old at the time. When I opened my eyes there was this cute little boy with a black plastic gun pointed at my face. "Bung bung!" he yelled, smiled, and then ran downstairs. I threw my covers off and chased him down. "Bung bung!" He yelled and laughed. After I caught him, he and I played simple video games on my IPad for hours. We would later nickname Zhuang Zhuang "door slammer" because he was always slamming the metal entry door to the living room as he passed back and forth from the courtyard. Crash! The metal door would slam shut. Crash…Crash! My Grandmother would have strung me up by my toes and made it impossible for me to sit down on my butt for a few days had I done that more than once and yet he did it over and over and over again.

A loudspeaker broadcasted music and event announcements from the school grounds that evening before dinner. It was blaring. I would find out the next day that these broadcasts occurred at 5:40 every single morning and evening. Because it was in a foreign language it seemed like an Orwellian propaganda broadcast. The announcements lasted thirty minutes every morning and evening and like a subtle brainwashing it gradually fit into my daily life.

Daibe Mountains in China from West Wind Buddhist Temple

The next morning, at 4:48, I woke up to birds singing. There was not another sound outside but chirping and chattering. No busy city sounds, car horns, emergency vehicle sirens, or even people talking. Nature's alarm clock buzzed in glorious tinnitus. The smell of flowers wafted into the bedroom like invisible smoke lifting me out of bed to the window. Outside I could see the tattered roofs of the first story below, the forested hills over the second story rooftops, and the moon hung low in the sky. At 5:40, the music started playing over the loud speakers echoing off the concrete buildings in all directions in symphonic dissonance.

Later, that same morning I watched the school kids all line up and walk to the cafeteria for breakfast with their tea thermoses and book bags. There were blue painted symbols and stick figures of people doing exercise on the walls around the running track. Qian had been doing so much interpreting for me during our trip that she said, "…and those blue figures are playing, soccer, basketball, and volleyball." I looked at her laughing and replied, "I am from planet Earth, not Mars." We both got a good chuckle out of that one and still laugh about it today.

For breakfast we had thousand year old eggs and various types of bread. The entire day was spent just kicking back, reading, and resting. That evening Qian's mother and aunt fixed noodles on the wood fired stove. Zhaung Zhaung and I stood together and watched the action first hand.

The next day Jixin, Wei, Xinping, Qian and I took a city bus to the dam at the Hualiangting Reservoir in the Daibe Mountains. The Tancheng-Lujiang (Tan-Lu) fault was abruptly obvious as we passed by the mountain front. The Dabieshan literally pops up from the plain. No alluvial fans or any sort of high angle slope in the topography. The mountain sides are covered in dense forest, rounded weathered granitic outcrops pop out from behind the trees, and tea farms line the drainages.

The Dabie Mountain range (Dabieshan terrane/ Dabieshan orogenic belt) is a complex, tectonically imbricated, fault-bounded block (Liu et al., 2003) in the Qinling-Tonbai-Dabie-Sulu orogen that trends west-northwest to east-southeast in east-central China. Elevation changes from west to east range from 1000 to nearly 6000ft including the high peaks of Mount Huo and Tiantangzhai, 5820 and 5673ft respectively. It is a prograde high-to ultrahigh-pressure metamorphic regime with blueschist and coesite-diamond bearing eclogite facies (Liou et al., 1989; Hacker et al., 1995; Wang et al., 2000). The block may have formed via intracrustal uplift of a crustal-scale dome formed by core-complex-type exhumation of the lower crust (Klemperer et al., 2003) during the Triassic-Jurassic north directed subduction of the northern edge of the Yangtze block and subsequent collision with the Sino-Korean craton (Zhai et al., 1988; Hacker et al., 1996; Wang et al., 2000). The metamorphic regime is intruded by voluminous Cretaceous plutons (Hacker et al., 2000) and is abruptly truncated to the east-southeast by the continental scale Tan-Lu fault with hundreds of kilometers of displacement (Jiawei and Guang, 1994; Gilder et al., 1999). The Tan-Lu fault is a complex structural feature due to the ramifications of the regional tectonics between the Sino-Korean and Yangtze cratons. It is currently a dextral transtensional fault (Zhang et al., 1995; Schmid et al., 1999) but has had normal and strike slip fault movements in the Cretaceous through Cenozoic (Ratschbacher et al., 2000).

At the Hualiangting dam boat launch there are excellent examples in the riprap of the metamorphic and granitic regimes this portion of the Dabie are composed of. Above the boat ramp, lining the sidewalks, were tables covered in small drying fileted white fish. Flies were buzzing around everywhere. Above the fish tables were clothes hanging from bamboo poles strung between flowering trees.

Down on the water, long metal ferryboats were tied down and lined up perpendicular to the riprap. Narrow, steep, concrete stairs lead down to the boats. The roofs of the ferries were a rusting maroon red with smatterings of orange and yellow. Each ferry had a captain's helm and wooden sides that

Ferry on Hualiangting Reservoir near Taihu, China

were painted a lovely cerulean blue. A single Chinese flag flew above the helm on each hulk. Most of the flags were brand new but others flew faded and torn. Some of the boats were in better shape than others. A few had blue tarps on the roofs held down with wood and stone, others had battered hulls, and one was half sunk. On each roof laid a single long wooden push pole, a few long wooden gangplanks, and yellow and white petals from the flowering trees above peppered the entirety.

We all boarded boat 118 bound for Siqianzhen at the far end of the lake. It was one of the better looking boats. We stepped from the rip rap up onto the boat deck. Two metal doors and a metal hatch were open to the gut of the vessel. On the doors in yellow symbols read the name of the town the ferry chartered to. From the entrance we walked down three red metal steps into the cavernous interior where it was dark and smelled like diesel fuel. It took a minute for my eyes to adjust. In the dark, a group of old folks with luggage and a young mother with child sat on long benches. The benches lined both sides of the hull and had blue fiberglass bucket seats screwed down into them. Under the benches were dozens of rectangular orange life vests that resembled a tangled mess of dead and decaying bloated Sponge Bobs. There were small square windows hinged with metal shutters. At the back end of the boat, through a narrow metal opening, stood the bedraggled captain smoking a cigarette next to the uncovered engine. When he fired up the engine, black exhaust poured out of the helm like smoke from an angry dragon's nostrils. He re-lit his cigarette and off we went into the blue.

The Hualiangting reservoir is the result of the dam, built in the 1960's, which traps the waters of the Chenghe River from part of the southwest Dabieshan watershed. The Chenghe is a tributary of the Yangtze. The dam was originally built for flood control, power generation, and agricultural irrigation and has since also evolved into a popular tourism location. The reservoir stretches dendritically NW-SE to NE-SW. Rectangular bamboo floating fish pens are everywhere in the lake. Tea farms, the occasional small village, and small temples dot the shoreline. The mountainous backdrop in every direction is verdant and changes colors in layered succession in the midday haze. From the blue water of the reservoir, to the dark and light green forested shoreline, the light blues, blues, light grays, and grays of the distant mountains all cast against the tan-light blue cloudless sky.

As the ferry puttered along past a flourishing promontory, off the shoreline sat a gigantic manmade lotus flower with golden petals and blue paracarpel. In the high mountains above, nestled in ovate weathered granite outcrops surrounded by lush woodland hid the visually pleasing West Wind Buddhist Temple.

The boat ramp at Siqianzhen had a lower angle than at the dam. It was also made riprap and had a wide cement staircase that led to flower gardens and trails. Upon landfall, the ferry hit the ramp with such force that an elderly woman nearly fell down and I thought the captain may have torn open the hull. The metal on rock smashing and scraping sound was unnerving at best. Atop the column of stairs the lovely flower garden bloomed. Behind the flowers was a large red banner. It was adorned with a picture of the Great Wall of China, white doves flying in the sky, strong muscular soldiers carrying the world, and a Hammer and Sickle beneath which was communist propaganda written in blocky yellow Chinese characters. I turned to watch the boat leave. At the water's edge was a little girl wearing a purple blouse dipping her feet into the water and smiling. A pathway from the garden led through the forest to a narrow road that opened up into the town.

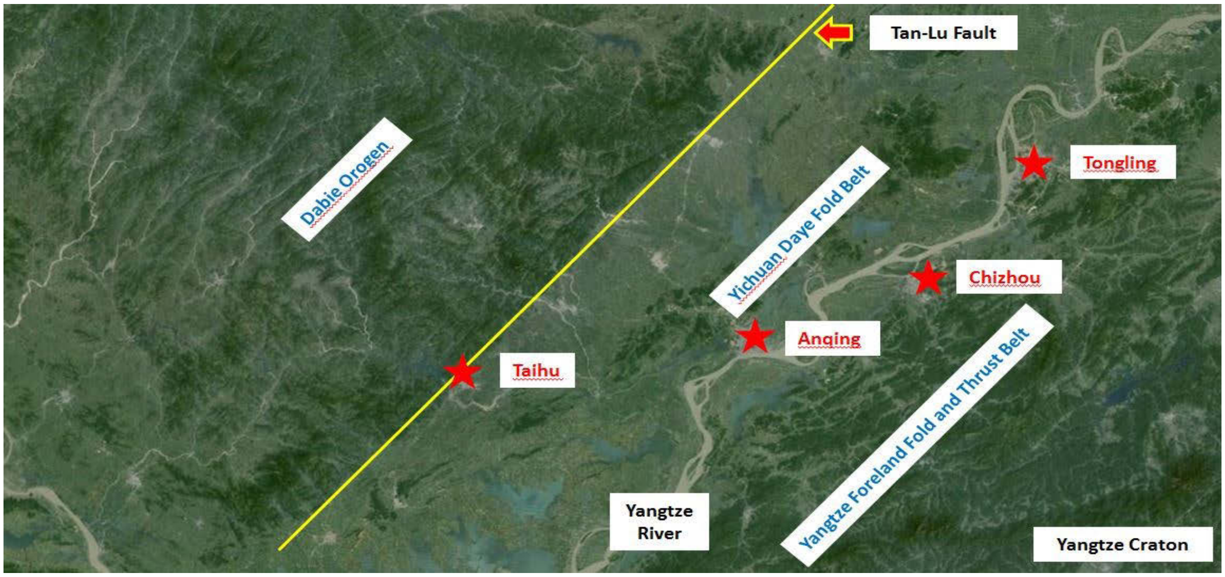
We wandered through Siqianzhen on sidewalks made of maroon, gray, white, and baby blue patterned paving stones. Placed on one of the sidewalks in front of a small store were knee-high screen-topped tables laden with wide bean noodles drying in the midday sun. We wandered into the store where a young woman with long straight and waste length black hair wearing a yellow dress was making the noodles. A little girl in the store sat frozen at a table. She was like a miniature mime staring at me with a mouthful of food.

We found a small restaurant in town. The owners took us down into their basement kitchen where we had a hot pot meal, rice, and tea. The owner smoked cigarettes and

Granite weathering pattern in outcrop near West Wind Buddhist Temple, Dabieshan, China

Gardens in Taihu, China and Dabieshan under rain clouds

Major Tectonic Provinces near Taihu, China



talked with us while we ate. The view out the back window spanned garden plots, a river, small row boats, and a line of white buildings that seemingly followed the river all the way into the mountains. It was pulchritudinous.

After lunch, sweating in the oppressive afternoon heat, we ambled back to the boat. We paid a small boat captain to take us back to the dam which was welcome relief from the dead air. The small boat ride was swift and very bumpy. I could feel through the soles of my shoes the fiberglass hull bending against the waves. I lost my orange BEG-RCRL ball cap in the wind. It's somewhere at the bottom of the reservoir now, drowned under a rain of sediment, rotting foliage, and dead fish.

Back at the dam, Jixin took a bus back to town. The rest of us snagged a taxi up to the Buddhist Temple. We entered through the main gate and hiked all around the ornate grounds viewing the red painted Buddhist messages carved in stone, statues, temples, gardens, and grottos. The entire area is sheltered in the forest like some kind of fairy tale vision with a splendid view of the reservoir below.

The original buildings date back to the Tang Dynasty. They were three black tiled and wooden-framed temples that faced westward. Only one original building remained and it was under remodel. The newer temples have red tiled double eve roofs resembling bamboo with red pillars supports all around. Beneath the eves are ornate and colorful sculptured designs and paintings of yellow and red dragons. The main walls of the temples are mustard yellow. The squares, fencing, and railings around the complex are all made of carved white syenite. Lining one of the squares are adorable small syenite sculptures of childlike, happy and smiling Buddha's sitting, studying and reading books. Someone had placed a book bag and a straw hat on one of them. It was darling.

The granite to gneissic-granite outcrops in the bamboo forest surrounding the temples is a pulsating visual sensation. They seemed to be alive. The rectilinear and sub-vertical chemical weathering patterns of the outcrops mimicked the natural joint patterns and resembled dinosaur scales.

Snout moths (*Hoenimnema yunnanensis*), fuzzy green caterpillars, spiny black caterpillars, giant black and yellow striped millipedes, and large toads were the only insects and animals I saw besides birds that I couldn't identify.

We hiked up moss covered stone stairs through the bamboo forests in the humid and dead air. The stair steps were surrounded by tan dry fallen leaves. Up the stairs to earthen trails and across granite outcrops we entered through The Bridge of the Immortal and Taibai Chess Room. Near the top was a huge open fracture in the granite. The massive slab was working its way down the mountainside on a glide plane. At the top was a precipice. At the edge was a single chain barrier hooked by hundreds of closed padlocks. Lovers go there and lock their padlocks to the chain and then throw the keys off the edge to symbolize there eternal and undying love for each other. I imagined a little furry moss covered forest creature with bamboo leaves for hair and big feet that lived in the rocks. I imagined him catching the keys as they fell and attaching them to his belt made of vines. Beneath the chain fence was a line of rust on the granite dripping off the edge like dried blood. The views spanned across the southwestern Dabieshan, the Hualiangting, and part of old Taihu.

The next morning for breakfast we had hot soy milk, rice cakes, sticky rice buns, thousand year old eggs, zongzi, and various breads. Afterwards I went to the farmer's market with Qian and Ruiying. The market is a wonderful place overflowing with people of all ages. Dried fish, various seaweeds, vegetables, fruits, eggs, meats, noodles, live chickens, dead chickens, fried rice cakes, fresh tofu, and fresh cooked dumplings are the typical fare. Small apples, pears, and lychee filled plastic milk crates to the brink. The vendor booths were replete with tomatoes, potatoes, green beans, peppers, bok choy, and other leafy greens. The colors of the scene patterned around like a paused kaleidoscope trapped in the synaptic gaps of Timothy Leary's mind. Men in army camo and bloody white aprons smiling and handling beef livers and kidneys stood behind long wooden butcher tables covered in sides of beef like a real world Mark Ryden oil painting.

At 4:30 that evening Qian and I went to speak to the middle school kids at the school. Jixin used to be the principle at the school and asked me if I would be willing to speak to the children. It was an honor to be asked and of course I obliged. I met with the Chinese English language teachers with Jixin first and then walked into a large classroom with roughly 90 to 100 boys and girls all clapping and smiling. There were two microphones set up for both Qian and I. We were introduced to the kids and then the floor was open for questioning.

The kids were great! 95% of them asked their questions in English and their English was outstanding. The other 5% asked Qian in Mandarin when trying to ask questions in English got them confused. I would answer their questions in English and Qian would repeat the answer in Mandarin. They had many intelligent and often funny questions, especially about American school kids. Like what kids their age did for fun, how they performed in school, was it true that American kids didn't study hard, was it true that American kids were dumb, was it true that American kids spent most of their time playing video games, and what kind of sports and hobbies did American kids enjoy. Some kids had more than one question and one of my favorites was the little girl that asked, "My parents don't want me to follow my dreams of becoming an artist. What should I do?" I replied to her the best I could, "It is a good idea to listen to your parents while you are living under their roof. Learn as much as you can in school and from them. They are looking out for your best interest. Then when you are an adult and making your own life choices it will be up to you to follow your dreams and do the right thing for you."

After the talk, two really sweet kids, one boy and one girl, came up to talk with me and brought small gifts. The little boy had sketched a picture of me in black pen while I had been talking. The little girl wrote me a cute little note that read,

Taihu Pu Chu High School Age Group Taihu, China

"You are cool, and fun, and very strong. I'll never forget you. ~ Sun Jiahui". That was just so freaking adorable.

We all went outside and took a group photo. Afterwards many of them asked me to sign my name in their schoolbooks. It was fun, flattering, and weird. I had never been in that kind of situation before. I signed as many books as I could before walking back to the house. I was only home for about ten minutes when three boys and one girl came over. They had small gifts for me and asked if I would be their friend. It was such a precious moment. "Of course I will be your friend!" I said. We then all went back to the track and played badminton for an hour. What a blast! They were shocked that a big fat redhead could play badminton!

After dinner the family and I took a long walk. It was after dark and there were thousands of people out walking around. The local squares were filled with people dancing to music in unison, playing with their children, talking, smoking, and having fun. We also wandered through the large cultural park. There was a massive golden statue of a sleeping Buddha backlit with changing colors of blue and violet and other visually stunning areas including the mountainous concrete sculpture of Laozi (Lao-Tzu) and temples lit up reflecting in water.

A few days later I was napping in one of the bedrooms upstairs when this god awful piano ruckus woke me up. I could hear people talking outside, car horns blaring, heavy machinery backing up, birds chirping, and that damn piano. I was plucked out of the most wonderful dream into a real life Jim Zorn album. It was a far cry from the beautiful awakening I had days earlier when the birds woke me up.

Later, we all went to Qian's uncle's place for lunch where I played with Zhaung Zhaung on the IPad. By now he was calling me "Uncle Jesse". "Uncle Jessa, Uncle Jessa!" he would say. He would sit on my lap and we would play little guy video games I uploaded until the cows came home. Every wall in the house had been scribbled on with markers, pencils, and crayons by little Zhaung Zhuang up to the height that he could reach. It was ridiculous but also hilarious. This is another instance where my Grandmother would have strung me up by my toes and likely made me chew and swallow crayons. Grandma didn't put up with much.

Speaking of masticating, I ate weasel for the first and last time EVER at lunch that day. Qian's uncle had put together this amazing spread of food. Everything looked delicious except that damn bowl of weasel. It was a dark brown greasy game meat. He trapped it himself and was really proud. I couldn't say no. I can tell you that it DID NOT taste like chicken! It was like eating an oily fatty stringy piece of fleshy dirt. It really freaked me out and I am a very adventurous eater. I never felt the same the rest of the trip after that. It changed me forever! All I really wanted from that day forward in China was a burger, fries, a coke, and a large pepperoni pizza with extra cheese! Needless to say, that didn't happen.

Behind the apartment complex was a large area of garden plots and wonderful views of the Dabieshan. The rain was coming down in sheets. I walked through the gardens under an umbrella with Qian's aunt as she pointed out all of the different vegetables she was growing. There was a single tree amidst that garden and in the distance clouds carpeted the mountains like the flowing hair of an angel off her shoulders.

We caught a city bus to "old Taihu" so I could see the places Qian grew up and where she went to school. The small bus was packed. Once we arrived in the old town, everything was wet. The roads were dotted with puddles and it rained off and on while we walked, sometimes so heavily that we would duck into a kiosk or under an awning. Before the dam was built, old Taihu was in the floodplain and flooded often. It was because if the flooding that Jixin convinced the local authorities to build a new school, which is where they live now.

The first place Qian and her family lived is now a crumbling elongate brick building that I thought no one in the world could live in but, people did still reside there. Garbage

Taihu Pu Chu Middle School Age Group Taihu, China.

Trail in the Dabie Mountains, China near West Wind Buddhist Temple

lined the streets, chunks of blue foam, cigarette butts, and discarded paper goods were strewn everywhere. Everything except the school grounds and local gardens were unkempt. It was a sad sight and reminded me of when I wandered through Compton, California as a young stupid white boy at the age of 20. It also reminded me of the tragic sight that is Midland/Odessa. Garbage is everywhere. The tile roof was disintegrating and some of the windows were broken out. There were wooden doors into what looked like single room dwellings. The sidewalk overhang was breaking apart and in serious trouble. A single uncovered light bulb clung to the brick wall above one of the entry door like a tick. The bricks were cracked, broken, and splattered with patching cement. An old gray haired woman sat hunched over in a chair at the end of the pathway in front of piles of junk. It probably wasn't junk to her. She was wearing a blue button down shirt, blue pants, white socks, and black shoes. She had her chin in her right hand, her elbow was resting on her right leg, and a cigarette was pinched between her fingers in her left, arm dangling between her knees. Next to her, clothes hung from wires between the bursting brick pillars. The gardens behind the pillars were the redeeming factor of nature's gift. They were amazing and plump with life force. There was a large swamp off to the left and a blue fence with white symbols behind the hundreds of individual raised garden plots. The white symbols read, "Implement Safe Production".

The second home that Qian grew up in was on local school property. As I had mentioned before, Jixin was a principle and so they lived on campus. This was the campus they escaped from due to the flooding threat. There were light blue and red brick sidewalks. Each brick was S-shaped. Blue topped ping-pong tables lined the sidewalks and scrubby weedy playing fields with soccer goals were the scene. Weeds grew up through cracks in the sidewalk and the white buildings were streaked gray-black with peeling paint. One building had a long blackboard on the side above which was a twisted and worn metal blue awning. There were pieces of colored chalk on the ground and drawings of childlike creatures, buildings, houses, and other scribbled creations on the board. Trees, palms, and what looked like rhododendrons lined the buildings and filled the courtyards. It was a quiet place. No once was around. The old single story long house that was Qian's second home was white with a multicolored tiled roof in front of a courtyard where there stood a large granite stone that read in Chinese characters, "Work hard!"

We walked for miles and miles through the old city. On one street hung a banner that asked the people to cremate themselves rather than be buried after death to save valuable land space. Everywhere we went people pointed and said, "Laowai". A little girl followed me for blocks until I turned around and spoke to her in Mandarin. She freaked out and ran away. Beautiful women, old women, skinny men, and old men looked at me and pointed. Colorful kiosks and multicolored umbrellas lined the streets. People were everywhere selling goods. Piles of fruit laid on blankets right on the sidewalk, plastic sandals, cooking pots, anything, and everything. The sky opened up and the downpour was torrential. We caught a taxi and on the way back home crossed the Chenghe River which was cloaked in fog. Men and women were working the gardens on the river banks in the rain.

The next morning I woke up at 5:00 and sent an email to Andrew Zimmern (Bizarre Foods) to let him know that I had just eaten freaking weasel. I don't think it ever reached him because I was sending Gmail from China and the Chinese are anti-Google. It was still pouring rain outside and the mountains were veiled in clouds. I went on a long walk and found front end loader piles of anthracite behind the school cafeteria. It was jet black, dense, and lustrous. I could see my hazy reflection in the cleavage as droplets of rain spattered on the surface.

A few days later Qian and I spoke to a group of over 100 high school students. Their questions were much more advanced and worldly than the younger group. They had some of the same questions about their American counterparts but, many of their questions had a more political bent. They asked about Obama, foreign policy, and questioned America's leadership in the world. Other kids asked about Iraq and Afghanistan. One kid asked me about my thoughts on Israel and Palestine. A young girl with big black rimmed glasses asked me what she should major in at university. Another girl asked me what I thought about the pollution in China, global warming, over fishing, and the exponential growth in human population. Another girl asked me if it was true that girls got pregnant in high school. Many of the kids were interested in America's national parks. They wanted to know if I had been to any and which

View of West Wind Buddhist Temple and the Hualiangting Reservoir

West Wind Buddhist Temple in the Dabieshan, China

ones to go to if they ever visited America. My favorite question was from two young ladies that had been giggling in the back row and whispering to each other nearly the entire time I'd been answering questions. One of them finally got up the courage to talk and giggling and ashamed asked me in Mandarin (Qian had to interpret), "How old were you when you first started dating?" I told them that my first significant girlfriend of any consequence was in high school. The entire room gasped out loud and started chattering amongst themselves. Apparently, the Chinese don't date in high school.

After the question and answer period, three young girls brought me some of the most wonderful paper-folding sculptures. Paper bowls, paper pineapples, and paper flowers all folded with intricate precision. They were too intricate and delicate to bring back to the states with me so I left them with Jixin.

Days later Qian's uncles took us to the bus station. We were hopping on a bus to Wuhu. I went to hit the can before boarding the bus. It was one of the most disgusting pissers I have ever seen. The entire bathroom was white tile. Brown and yellow on white is not a pretty picture. There were dozens of stalls with no toilets or doors. A narrow long rectangular tile trench ran between the stalls where people were squatting and dropping number two. A stream of water ran down the trench and down into a hole at the end of the stalls. There weren't any urinals either. Basically you just urinated on the wall which ran down into another trench. I'll let you imagine the wretched smell of that place.

Stay tuned for the next and final installment of my trip to China. Jesse's Jaunts, China Part 4! I look forward to finalizing this section of my writing and moving on to my trip to Iceland.

Jesse Garnett White was raised in Chewelah and Spokane, Washington. He obtained his bachelor's degree in geology from the University of Idaho and his master's degree in geology from the University of Alaska, Fairbanks. Jesse is currently unemployed, actively seeking meaningful and challenging work, traveling the world, and loving every minute of it.

This article is dedicated to a few different groups of people.

First, I would like to dedicate it to Dennis and his son Ryan who I met at the last WTGS luncheon meeting in Midland. Dennis is a faithful reader of Jesse's Jaunts and I appreciated his kind comments concerning my articles. Second, it is dedicated to Caley Lepaire who is *totally awesome* and acting as the current WTGS editor. I am fortunate to work with her. Finally, it is dedicated to the good folks I am working with on the 2015 WTGS Annual Symposium committee (Paula, Daphne, David T., Valentina, Curtis, Jeff, Sam, Sergio, Haleigh, Dave C., and Meg). Thank you all for your commitment to our growing society and for your kindness and friendship in the wake of Garnett Kirby White's death.

This article truly goes out to Qian Li. Without you my dearest love and friend, I am a Pisces lost in the Mariana Trench. 1000 paper cranes…

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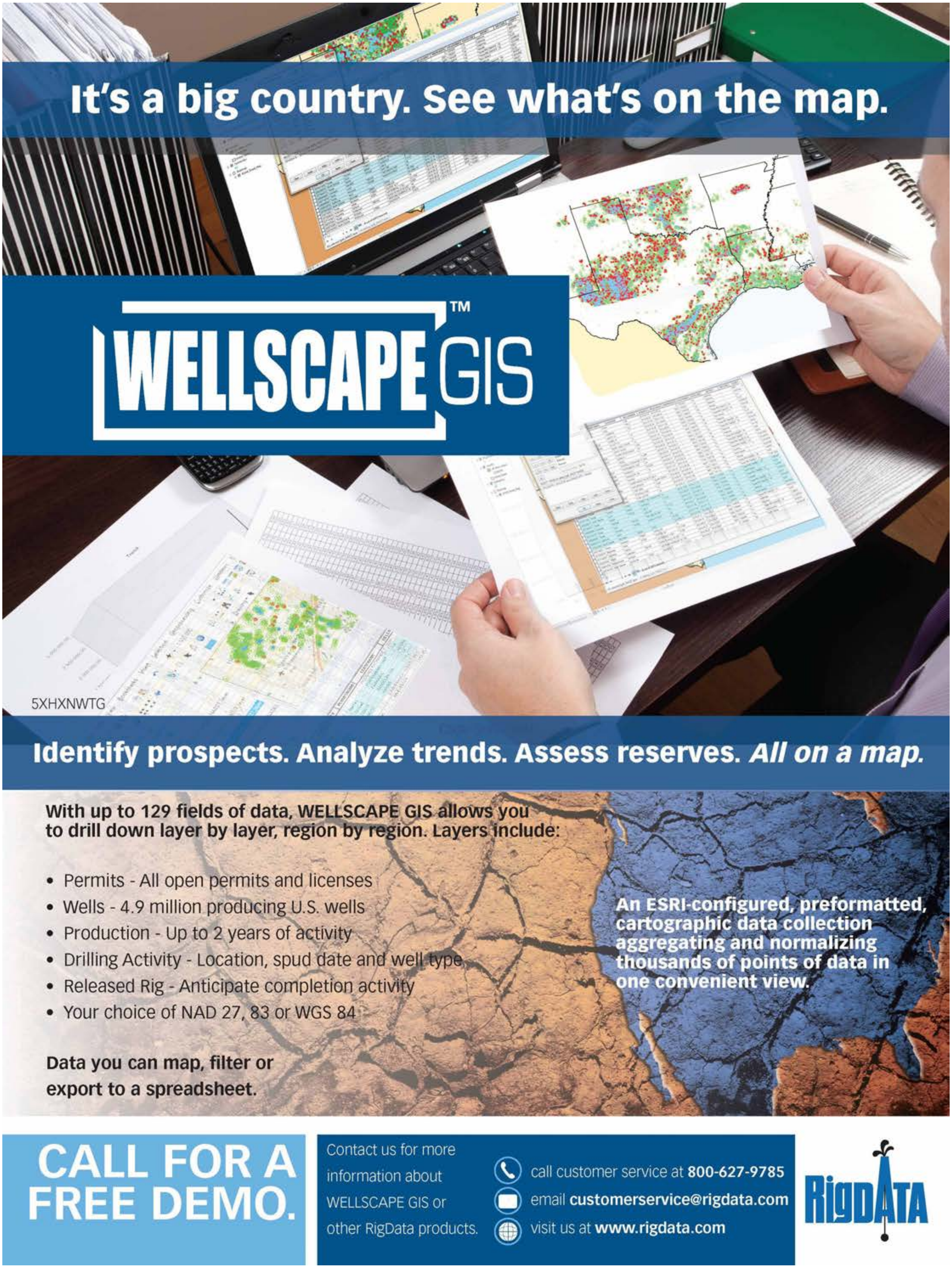
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