The Geology of the Timbered Hills Group in Oklahoma

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Abstract

The Timbered Hills Group unconformably overlies the igneous basement in Oklahoma and consists of two formations, the lower Reagan, and the upper Honey Creek. With the exception of the highest "hills," the Reagan Sandstone covers the eroded Carlton Rhyolite in southwestern Oklahoma and various other igneous rocks throughout the rest of the state. It grades up from nonmarine sands to marine sands, capped by a widespread glauconitic "greensand." The Honey Creek conformably overlies the Reagan and unconformably overlies all but the highest remaining hills of the igneous substrate. It is composed of interbedded pelmatozoan grainstones and quartz sands, which grade up into the pure carbonates of the overlying Arbuckle Group. Evaluation of published field data indicates that the physical features of the two formations can be explained readily within the framework of the Genesis Flood. The Reagan contains the boundary between the freshwater and marine phases of the early Flood. The Honey Creek marks the transition from clastic deposition to the continent-scale North American carbonate platform that apparently formed early in the Flood.

Introduction

The previous paper in this series (Reed, 2004) described the igneous basement of Oklahoma: its lithology, structure, and proposed uniformitarian history. It proposed the formation of the igneous basement during the creation week, but recognized that an important tectonic feature of the southwestern part of the state, the Southern Oklahoma Aulacogen (SOA), could have formed at the beginning of the Flood. The SOA is a fault-bounded downwarp filled by bimodal igneous rocks, including rhyolites and sheet granites over mafic intrusives. Events of this period are obscured by later tectonism which splintered the SOA into several uplifts and basins (Figure 1).

Both within and without the SOA, a thick, predominantly carbonate, lower "Paleozoic" sedimentary sequence overlies the igneous basement in Oklahoma. These carbonates can be correlated across much of the North American midcontinent, but reach their greatest thickness in the SOA, the depocenter of a broad downwarp known as the Oklahoma Basin during the lower and middle "Paleozoic" (Johnson, 1988). The upper "Paleozoic" marks the tectonic breakup of the large midcontinent platform into sharply delineated, fault-bounded basins infilled predominantly by clastics.

This paper will describe the basal sediments in Oklahoma. They are classified as upper Cambrian, and the same vertical sequence occurs over most of the midcontinent in North America: (1) igneous basement, (2) an erosional surface, (3) a blanket sandstone, grading to (4) mixed carbonate and clastics, and finally to (5) relatively pure carbonate. In Oklahoma, the basal unit is the "Reagan Sandstone;" in

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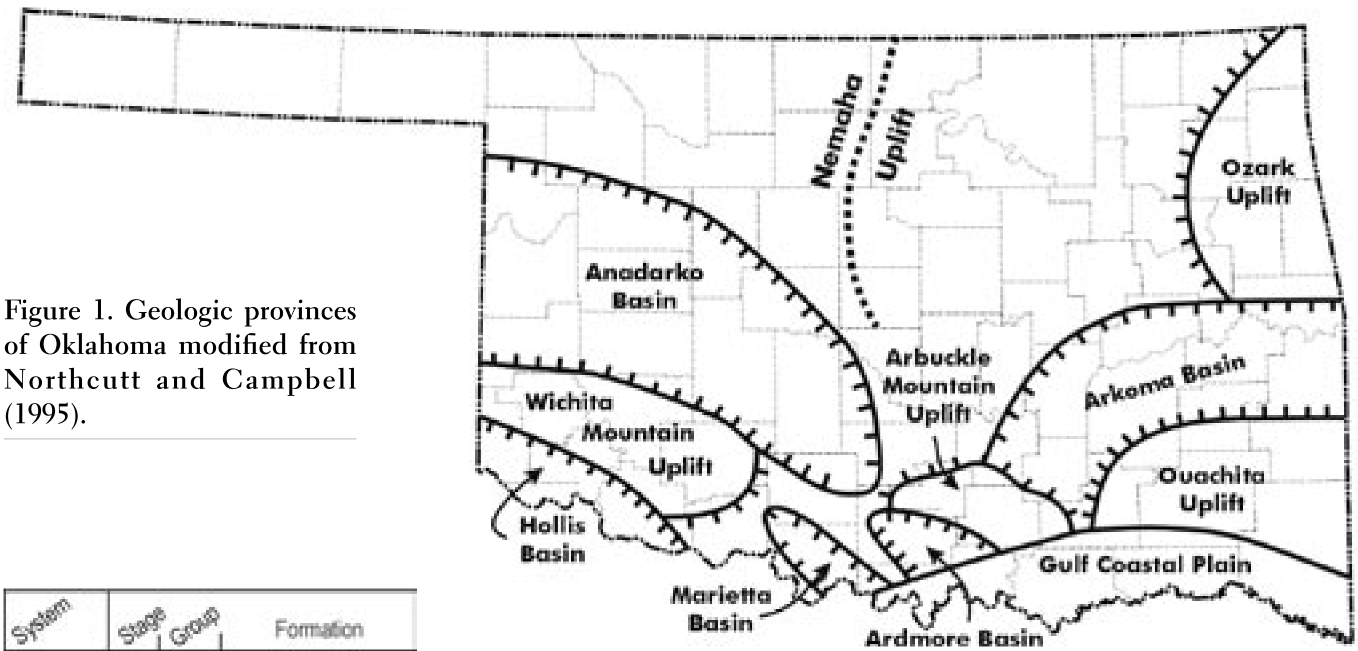

Figure 1. Geologic provinces of Oklahoma modified from Northcutt and Campbell (1995).

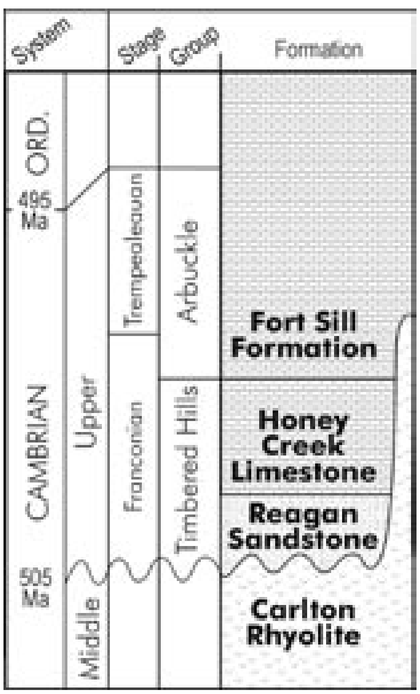

Figure 2. Stratigraphy of the Timbered Hills Group modified from McElmoyl and Donovan (2000).

other parts of the midcontinent, it is called the "Lamotte," the "Hickory," or the "Mount Simon." In Oklahoma, the Reagan grades up to the Honey Creek Limestone (Figure 2). The substrate for the Reagan in the SOA is the Carlton Rhyolite (Donovan, 1995), but outside the SOA, the sandstone unconformably overlies Precambrian granite, gneiss, and rhyolite.

The Timbered Hills Group in turn is overlain by the regional carbonate sequence of the Arbuckle Group (i.e., it is correlated to the Ellenburger Dolomite in Texas and the Knox Dolomite in Tennessee). The Timbered Hills and Arbuckle groups range in thickness to more than 3,000 m (~10,000 ft) of shallow marine carbonates with a few interbedded sands and shales, deposited in a broad epicontinental marine setting that covered much of the region (Figure 3). This study summarizes published descriptions of the strata, attempts to dissect the uniformitarian interpretation from that description, and then develops an alternate explanation consistent with biblical history. Other interpretations are certainly possible within the biblical worldview, and the additional work of other creationists to refine and correct the conclusions of this study is welcome.

The Ouachita Trough

The coastline at the time of the Cambrian transgression is thought to correspond roughly with the Ouachita Front, a regional series of "late Paleozoic" thrust faults transporting a thick clastic section, interpreted as deep water clastics, over shelf carbonates. Somewhere in southeastern Oklahoma (now obscured by the thrusting) was the boundary that is perhaps analogous to the shelf-slope transition of modern oceans. Prior to thrusting, geologists envision the Ouachita section as a deep marine trench. The Timbered Hills Group has not been encountered in outcrop or by drilling in the Ouachita province (Johnson, 1991). Because the boundary is profound, regional, and lithologic, it may well represent the shoreline at the time of the Flood (Figure 3).

Southeastern Oklahoma comprises some of the most complex geology in the world. The apparent northward transport of multiple allochthonous sheets, combined with significant structural deformation resulted in tight folding, overturned strata, imbricate thrusts, and repeated section; these various factors hinder accurate stratigraphic reconstruction of the offshore Ouachita section, despite numerous wells, seismic lines, and years of study. In addi-

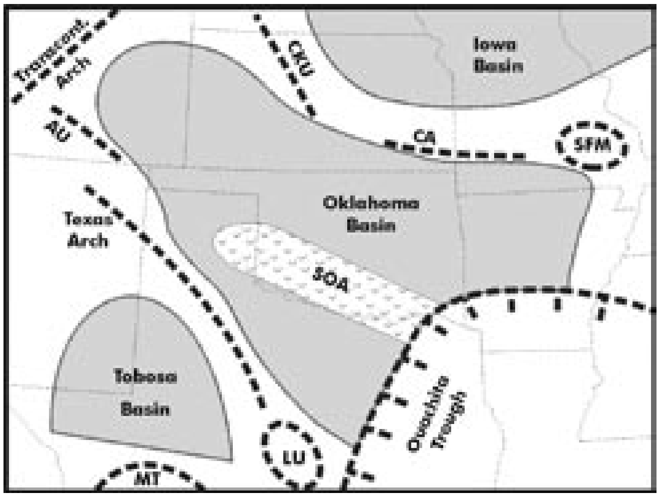

Figure 3. Extent of "lower Paleozoic" Oklahoma Basin and its relationship to the Southern Oklahoma Aulacogen modified from Johnson et al. (1988). CKU = Central Kansas Uplift, CA = Chautauqua Arch, SFM = St. Francois Mountains, LU = Llano Uplift, MT = Marathon Trough.

tion, the clastics are lithologically similar and it is difficult to correlate deepwater clastics to the predominantly shelf carbonates.

> Because of these problems, it is virtually impossible to produce a composite stratigraphic section or a standard reference section of the Ordovician Ouachita facies with which to correlate. (Suhm, 1997, p. 27).

Gatewood and Fay (1991) discuss the Ouachita-Oklahoma shelf boundary and correlation between the Ouachita clastics and shelf carbonate. Further discussion of the Ouachita Front will be deferred to another paper.

Summary of Basement Surface

If the geological activities that formed the majority of the Oklahoma stratigraphic section occurred during the single year of the Genesis Flood, then a close relationship should be discernable between successive elements of the vertical sequence. If the tectonic and magmatic episode that formed the SOA occurred at the onset of the Flood, then the relationship between the basement igneous rocks and the subsequent sediments must have been much different from that envisioned by uniformitarians.

> Neither age nor compositional boundaries of these Precambrian rocks appears [sic] to have had a substantial effect on Paleozoic history. (Johnson et al., 1988, p. 310).

Uniformitarians envision a long period of intense tropical weathering of the Wichita igneous complex based on its paleogeographic location relative to the equator (McBee, 1995). There is little direct evidence of this belief other than the irregular topographic surface. The topography of the basement can be observed in outcrop in the Wichita and Arbuckle Mountains with relief up to 300 m (1,000 ft) in the Slick Hills (Donovan, 1995). The slopes of the basement hills in outcrop are gentle, but prior to sedimentation, the rhyolite was apparently tilted ~5°, intruded by diabase dikes, and cut by north-south faulting before sediments were deposited. Donovan and Burcheit (2000) noted a pre-Reagan dip of 22° in the Slick Hills. These data are consistent with synchronous tectonism and magmatism, followed immediately by sedimentation.

Outcrops provide direct observation of the igneous substrate in the Slick Hills.

> Most exposures weather red-brown; the most common lithology is porphyritic lava; phenocrysts are either feldspar or quartz. In most of the rhyolite exposures, flow structures have been observed. (Tsegay, 1983, p. 17).

Donovan and Stephenson (1991) noted that the Carlton surface underwent rapid subsidence and saw no evidence of the rhyolite being elevated relative to the craton. Additionally, they noted that the topography was rugged outside the SOA, too; to the north are the "Tulsa Mountains," and the map of the basement surface (Reed, 2004, Figure 3) shows irregular topography. From a regional perspective, however, the basement surface shows another face.

> The surface on which the Cambrian seas transgressed was generally of low relief (about 100 m), supported by a heterogeneous suite of mostly granitic igneous rocks swept clean of any significant debris. (Johnson et al., 1988, p. 310).

Thousands of square kilometers of igneous basement were "swept clean" prior to Reagan deposition. That statement deserves much greater consideration than given by uniformitarian geologists; one does not often see vast areas of continental basement "swept clean" as a matter of course. The extent and amount of erosional energy required to do this is certainly elevated relative to processes operating today. Also, stripping the basement down to granite over most of the continent speaks to a rapid event, since even a few millennia of weathering, erosion, and redeposition would recover the clean basement surface with sediment and soils. Thus, the extent and efficacy of erosion combined with the widespread deposition of the Reagan and its correlative sands speak to the scale and rapidity of both events.

Another distinction between uniformitarian and creationist approaches to the initial sediments lies in the timing of the magmatism of the SOA. If it occurred as a result of the initiation of the Flood, heat flow would have been elevated during early sedimentation, and we would expect significant geochemical activity due to magmatic outgassing, resulting in local, dramatic changes in pH and Eh.

Timbered Hills Group: Reagan Sandstone

General Extent and Geometry

The Reagan Sandstone covers the basement of most of Oklahoma and extends across most of the midcontinent under the various names mentioned above. It is absent only over topographic highs in the basement, such as the Tulsa Mountains (Figure 4) and highs in the Wichita and Arbuckle Mountains (Johnson, 1991). In some areas the absence may be the result of nondeposition and in others, later erosion. Often it is impossible to tell. The Reagan and its equivalents are present in a vast number of wells and are exposed in outcrops in the Arbuckle and Wichita Mountains in southern Oklahoma, in the St. Francois Mountains and Ozark Uplift in Missouri, and in the Llano Uplift in Texas (Johnson et al., 1988). The initial post-basement sediments are more complex at the Llano Uplift, where more than 300 m (1,000 ft) of marine clastics were deposited, and much of those sediments are dated earlier in the Cambrian (Dresbachian) than the Reagan. The SOA forms an abrupt northern boundary for these thicker clastics; the Reagan is commonly less than 60 m (200 ft) in thickness (McBee, 1995).

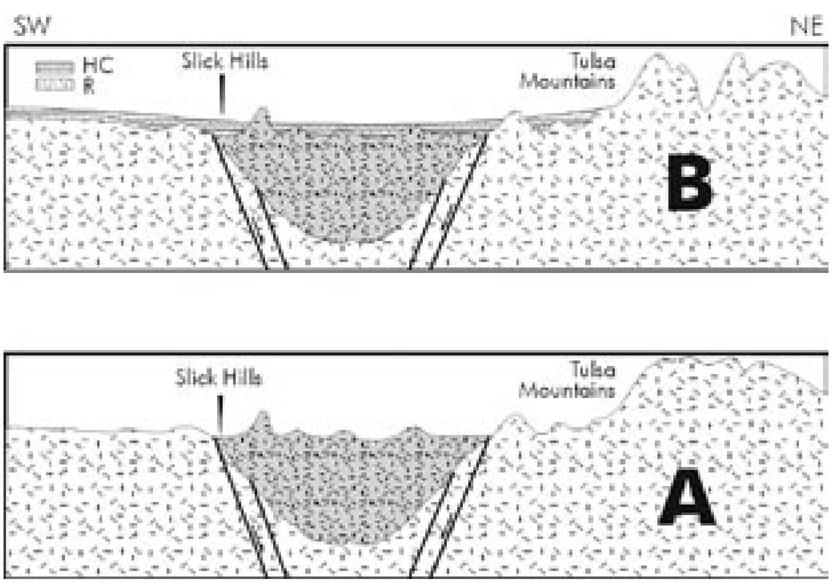

Figure 4. Cross section of the Oklahoma basement (A) before the Timbered Hills transgression, and (B) following Timbered Hills sedimentation. Igneous fill in center represents SOA. R = Reagan Formation, HC = Honey Creek Formation. From Hosey and Donovan, 2000.

The Reagan is time transgressive to the northwest (Johnson et al., 2000). The Cambrian transgression migrated in that direction over Oklahoma from the Cambrian continental margin (probably near the Ouachita front), depositing 15–76 m (50–200 ft) of sand over most of the state (Johnson, 1991), but greater thicknesses of 23–137 m (75–450 ft) in the Arbuckle region (Ham, 1973). This remarkable uniformity of sediment thickness and composition speak to similar depositional processes across the entire area, especially in light of the irregularities in the basement surface that are in places greater than the thickness of the formation.

Even more remarkable, this relatively thin vertical sequence from the basement into the Paleozoic is similar across much of Texas, Oklahoma, Kansas and Missouri (Donovan, 2000b). The basal sand is generally feldspathic and glauconitic, consisting of reworked detritus eroded from the igneous basement, and quartz sand from the cratonic interior. Depositional conditions over the same area changed drastically immediately after the Reagan; thousands of feet of almost pure carbonate were deposited over much of North America. The transition between the siliciclastics of the Reagan and the pure carbonates of the Arbuckle Group in Oklahoma is the Honey Creek Formation, which ranges between 30 and 90 m (100–295 ft) thick.

The Timbered Hills and Arbuckle Groups are better exposed in the Slick Hills (Figure 5) than in the Wichita and Arbuckle Mountains (cf. Figure 1, Donovan, 1986), and better in the eastern Slick Hills than in the western. Donovan (2000b, p. 48) stated: "The exposure quality is high, and facies variation can be adequately assessed." Thus the descriptive sections in this paper are heavily weighted to the Slick Hills outcrops. The eastern Slick Hills exposes a homoclinal section that dips 20°–50° NW over almost ten miles of outcrop (Figure 6). The thickest Reagan in this area is associated with minimal relief; basement showing greater relief is overlain by thin Reagan beds (Tsegay, 1983).

Composition

Stitt (1973) describes the Reagan in the Arbuckle region as a fine to medium-grained, red-brown to white, glauconitic arkose, a composition mineralogically similar to the basement. Its lower beds are discontinuous where interrupted by the irregular topography at the onset of the transgression. In the Slick Hills

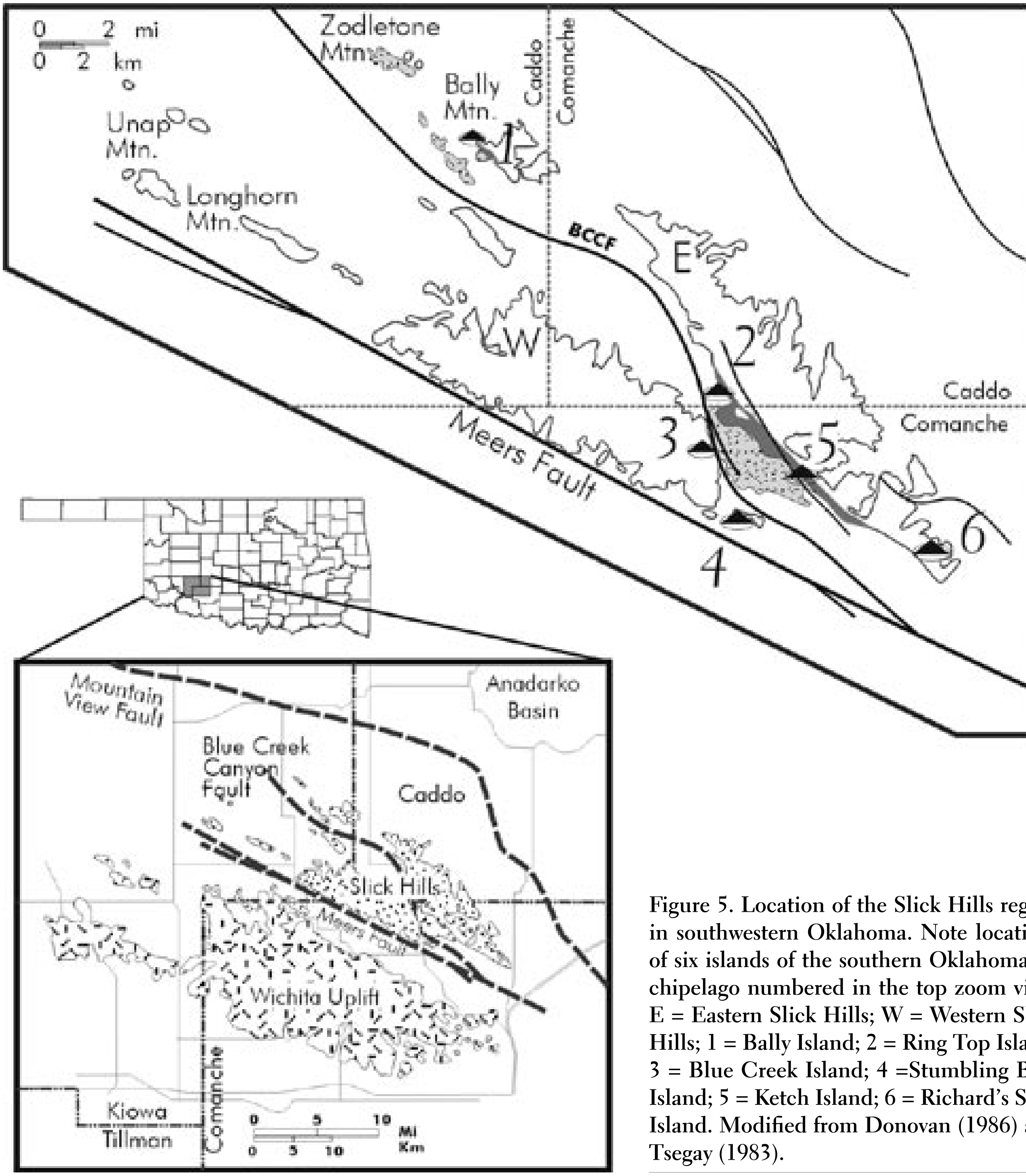

Figure 5. Location of the Slick Hills region in southwestern Oklahoma. Note locations of six islands of the southern Oklahoma archipelago numbered in the top zoom view. E = Eastern Slick Hills; W = Western Slick Hills; 1 = Bally Island; 2 = Ring Top Island; 3 = Blue Creek Island; 4 =Stumbling Bear Island; 5 = Ketch Island; 6 = Richard's Spur Island. Modified from Donovan (1986) and Tsegay (1983).

region, this surface formed islands which are known as the "southern Oklahoma archipelago." Although trilobites (mostly fragments) are present in the middle and upper parts, no body fossils are found in the basal beds.

Tsegay (1983) described seven facies of the Reagan in the Slick Hills. These included: (1) basal and fringing conglomerates and Breccio-conglomerates; (2) lithic sandstone; (3) red-brown orthoquartzite (sandstone composed almost entirely of quartz grains); (4) purplish-red orthoquartzite; (5) tan (buff) orthoquartzite; (6) green (glauconitic) sandstone; and (7) green shale. In more recent publications, this empirical classification has been diluted by interpretation,

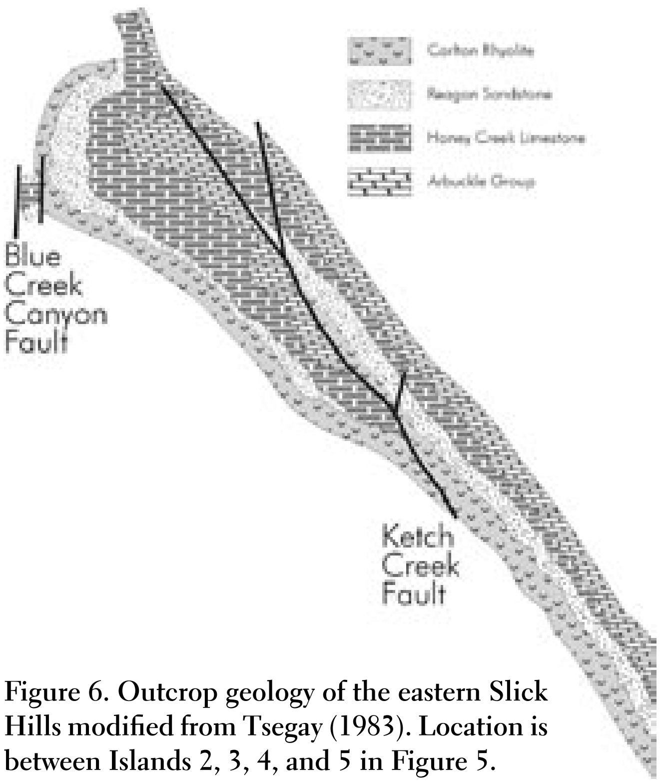

Figure 6. Outcrop geology of the eastern Slick Hills modified from Tsegay (1983). Location is between Islands 2, 3, 4, and 5 in Figure 5.

as is demonstrated by the use of interpretive terminology below. This "evolution" is an example of how descriptive work is submerged beneath interpretive and the two are seldom divorced.

The "interpretive" facies of the Reagan Sandstone fit into a general vertical sequence of lower (1 below), middle (2–4 below), and upper (5 below) parts of the formation. The facies include:

1. *Detrital Alluvial Facies.* Donovan (1986) described the basal deposits of the Reagan as red-brown, poorly sorted conglomerates and sandstones that overlie the irregular topography of the basement, and fill channels cut into the rhyolite. He interpreted this facies as alluvial talus and braided stream sediments. This facies is approximately 12 m (40 ft) thick in the Slick Hills area and is composed of sediments that have been locally eroded and redeposited. The basal conglomerates are most commonly found in valleys and channel deposits and are usually less than 2 m (6.5 ft) thick. Individual beds, which are poorly sorted and show no sedimentary structures, range up to 1 m (3 ft) thick. The matrix in the lower beds is rhyolite debris, in contrast to the glauconite, phosphatic shell debris, and mature quartz in the upper beds (Tsegay, 1983).

   Rhyolite conglomerates are found fringing the hills at all levels in the Reagan, but are laterally restricted. Rhyolite pebbles and cobbles range up to 15 cm (6 in) in diameter, decrease in size up section, and are glauconitized in the beds of the upper formation (Tsegay, 1983). Red-brown orthoquartzite is restricted to one locale, with small-scale trough cross beds and horizontal laminations. Tsegay (1983) shows this facies stratigraphically beneath the shoreline facies sands. A significant component (up to 15% of the whole rock) of this facies is iron in the form of hematite cement (Cloyd et al., 1986; Tsegay, 1983). Iron is present in all facies of the Reagan in various forms including iron-rich illite, replacement ankerite, glauconite, pyrite, and siderite, as well as intraformational ferruginous ooids and glauconite peloids.
2. *Shoreline Facies.* Fine to coarse-grained, well-sorted, occasionally pebbly quartz sandstone overlies the alluvial facies. These sands are purple (hematite cement) and tan (silica cement). Up to 15% ferruginous ooids (deformed against quartz and rhyolite grains during diagenesis) are present as well as traces of plagioclase and microcline (Donovan and Burcheit, 2000). The ooids are composed of alternating bands of hematite and illite. A photo from Tsegay (1983) showed a 1-mm ooid composed of a silt particle nucleus surrounded by alternating bands of hematite and illite. This ooid and many others were deformed by compaction prior to cementation. These sands are interpreted as tidally influenced shoreline sands derived from the craton (Donovan, 2000b).
3. *Lenticular Sandstone Facies.* Much of the middle Reagan is composed of lenticular bodies of quartz sandstone up to 10 m (35 ft) thick. They are composed of up to medium to large-scale cross beds (Donovan and Ragland, 1986) and show an upward decrease in both grain size and bed thickness (Tsegay, 1983). The sandstone is composed of dominantly unstrained quartz with some rhyolite clasts, glauconite peloids, ferruginous ooids, and phosphatic debris. Reactivation surfaces are common across the faces of cross beds, and vertical burrows of the *Skolithos* ichnofacies are present in small scale cross beds. Cross beds show bimodal and bipolar paleocurrents to the NW-SE, with asymmetric frequency to the SE.

   > On the assumption that the transgression was to the northwest… flood tides were evidently less effective than ebb tides in moving sediment. In other words,

> the adjacent craton was a net contributor of large volumes of siliciclastics to the transgressing seaway. (Donovan, 2000b, p. 49).

Tsegay (1983) notes that cross beds in the purple facies show evidence of rapid deposition (steep bed angles) and variations in the strength of the current flow. Both of these observations support a Flood scenario.

4. *Heterolithic Sequence Facies*. Gray-green shale is interbedded with the middle and upper Reagan sandstones. At Bally Island, these shales are present immediately above the first middle Reagan shoreline sands. The shales are composed of olive green illite. Like the sandstone bodies, the shaly interbeds also show small-scale, bipolar lenticular bedding and horizontal burrows. No organic carbon is present.
5. *Green Sandstone Facies*. The upper part of the Reagan Formation is a distinctive widespread green, fine to coarse-grained, peloidal, quartzitic sand that receives its distinctive color from up to 60% glauconite peloids mixed with quartz sand, phosphatic nodules, rhyolite grains, and up to 10% phosphatic brachiopod parts (*Lingula* sp.). Glauconite is also present as an alternation of rhyolite clasts, and is illitic rather than smectitic in composition (Tsegay, 1983). An orange, iron-rich illite matrix is present in the lower beds of the greensands, except at Zodletone Mountain (Figure 5) where excess iron allowed the development of a glauconite matrix (Tsegay, 1983). There is a positive correlation between glauconite peloids and phosphatic fragments, interpreted as evidence for an organic origin of the glauconite from the brachiopods and other fauna (Donovan et al., 2000), but bioturbation is much less abundant in the upper sands compared to the middle sands. The absence of *Skolithos* in the upper greensands may reflect deeper, less oxygenated water. Some outcrops reveal bipolar cross bed sets up to 1.5 m (5 ft) thick. *Cruziana* ichnofacies are also present (McElmoyl and Donovan, 2000), but at Bally Island, the cross beds are only ~30 cm (12 in), indicating lower energy. Conversely, rhyolite conglomerates are more abundant at Bally Island in this facies, where six individual layers of rhyolite conglomerate with pebbles and cobbles up to 15 cm (6 in) thick are present.

The typical vertical sequence of these facies includes a basal unit of the detrital alluvial facies, a middle unit including tidally-influenced lenticular and shoreline facies, interbedded with the heterolithic sequences, and finally a widespread upper greensand faces (Figure 2). The middle unit includes coarse-grained purple and brown, medium scale trough cross-bedded quartz with hematite and quartz cement, covered by a tan to light brown sandstone with abundant *Skolithos* with tapering and slightly sinuous burrows ranging up to 15 cm long and 1 cm across. *Arenicolites* U-shaped burrows are also present (Tsegay, 1983).

Sedimentary structures in the Reagan Sandstone are dominated by the small to medium-scale trough and planar cross bedding in sets up to 2 m (6.5 ft) thick. Paleocurrent directions from the cross beds in the purple sand facies are unimodal to the SE; those in the greensand are bimodal, dominantly to the SE and subordinately to the NW (Tsegay, 1983). The bimodal cross beds are considered strong evidence for a tidal style environment.

Understanding of diagenesis in the Reagan is complicated by the later uplift and reburial during "late Paleozoic" time. Pre-cement porosity in the Reagan is quite high, suggesting early cementation. The lower Reagan sands are cemented by particulate hematite covered by syntaxial quartz overgrowths. Hematite cements persist into the middle Reagan but silica cement is also present, both with and without hematite. In the middle sands there was sufficient time prior to cementation to compact the ferruginous ooliths against the harder grains. Higher in the formation, hematite is absent and silica cement is not well developed. In the greensand facies, an iron-rich illite matrix inhibited cementation; peloids show greater compaction and the greensands weather more easily than the lower facies. A change in cement chemistry occurs just below the top of the formation, where calcite and ankerite cements are present. The introduction of carbonate cements probably resulted from infiltration of carbonate-rich fluids downwards from the Honey Creek.

The contact between the Reagan Sandstone and Honey Creek Limestone has been moved up and down the section during its history (McElmoyl and Donovan, 2000), but is presently placed at the level of the first bioclastic grainstone. The lowest Honey Creek beds include abraded and broken pelmatozoans (echinoderms) and minor shell debris, with reworked quartz, rhyolite, glauconite, and phosphate grains.

> Although a few grains appear toward the top of the Reagan Sandstone, the widespread incoming of bioclastic grainstones is taken as the base of the Honey Creek Limestone. (Donovan, 1986, p. 2).

A diagenetic reaction between carbonate and glauconite formed a distinct orange ankerite layer at the boundary of the Reagan and Honey Creek (Donovan and Ragland, 1986). This phenomenon occurred when iron-silica cementation gave way to iron-silica-carbonate cementation.

(Cloyd et al., 1986). Ferrous iron was incorporated into the existing carbonate grain lattices resulting in coarse crystalline ankerite forming euhedral rhombs. This diachronous boundary (Donovan, 2000b) ranges from 0.6–4.6 m (2–15 ft) thick and persists throughout Slick Hills, an area of over 48 km^2 (30 mi^2). The thickness variations of the ankerite zone are attributed to varying permeability of the sediments during diagenesis (Cloyd et al., 1986). Although the ankerite contact is commonly sharp, it does not always correspond to bedding. Ankerite replacement occurs both with and without the destruction of previous bedding.

Timbered Hills Group: Honey Creek Limestone

General Extent and Geometry

The Honey Creek Limestone overlies the Reagan Sandstone with no apparent erosional boundary and unconformably overlies the Carlton Rhyolite where the Reagan is missing. Examples of Honey Creek-Carlton contact are visible in the Blue Creek Canyon and Bally Mountain (c.f. Figure 5) areas of the Slick Hills (Rafalowski, 1982). The base of the Honey Creek is defined by the first marine pelmatozoan-rich grainstones (Donovan, 1986), and the Honey Creek is conformably overlain by the Fort Sill Formation of the Arbuckle Group. The introduction of carbonate is significant: "Ultimately, the area became part of the immense Late Cambrian-Early Ordovician microtidal carbonate platform that circled the Laurentian craton." (Donovan et al., 2000, p. 40). The contact between the Honey Creek and the Fort Sill Formation is defined by the first occurrence of persistent carbonate mud. Both the upper and lower Honey Creek contacts are visible and laterally continuous in outcrop.

Like the Reagan, the Honey Creek Limestone is exposed in outcrops of the Slick Hills, the Wichitas, and the Arbuckles in Oklahoma. Rafalowski (1982) found five good exposures in outcrops in the Slick Hills. Based on lithology, fauna, and sedimentary structures, the formation is subdivided into three informal members: "upper" and "lower" members, divided by a discontinuous "red limestone" member defined by McElmoyl and Donovan (2000). In the Slick Hills, the Honey Creek Formation ranges between 37 and 91 m (122–300 ft), has an average thickness of 60 m (200 ft) and thins to the northwest (Donovan and Ragland, 1986). In the Arbuckles, the formation is only 30 m (100 ft) thick, but it thickens to ~70 m (225 ft) and is dolomitized on the craton (Ham, 1973).

Uniformitarians use biostratigraphic correlation (trilobite fauna) to equate the Honey Creek with the Davis Limestone in Missouri; various members of the Wilberns Formation in Texas; the Franconia Formation in Wisconsin and Minnesota; the Deadwood Formation in South Dakota; and Copper Ridge Dolomite in Georgia, Alabama, and Tennessee. Rafalowski (1982) provided a concise historical summary of the stratigraphic studies in the area.

Composition

The Honey Creek Formation is "a resistant, coarsely-crystalline, glauconitic, bioclastic limestone interbedded with tan to brown, fine-grained, glauconitic, calcareous, bioclastic sandstone and green shales." (Rafalowski, 1982, p. 47). Stitt (1973) described the formation in the Arbuckles as a gray, fossiliferous, glauconitic biosparite. Rafalowski (1982) identified three components of the Honey Creek: siliciclastics, allochems, and authigens, as well as related sedimentary features. The distribution and nature of these in the Slick Hills are shown in Table I. The grainstones are well washed and cross-bedded (Donovan and Ragland, 1986) and the beds in the formation vary from pure bioclastic grainstone to mixtures of quartz, carbonate, rhyolite, phosphatic debris, and glauconite. The siliciclastic fraction increases upward through the formation to a layer called the "quartz spike" towards the top of the formation, before decreasing dramatically (Figure 7). In contrast to the Reagan, the Honey Creek contains very little detrital clay (Donovan et al., 2000), but is well cemented with virtually no porosity (Rafalowski, 1982).

The formation contains abundant small to medium-scale, planar, trough, and herringbone cross beds with NW-SE bipolar trends (similar to the Reagan) and many reactivation surfaces (more dominant in the lower formation). However, while the cross bed sets of the Reagan range up to 2 m (6.5 ft), those of the Honey Creek seldom exceed 23 cm (9 in). The alternating laminae are both planar and wavy. Bed boundaries between the two grain populations have been altered during diagenesis by pressure solution and stylotization of the carbonate grains (Rafalowski, 1982). Faunal diversity increases upward from the Reagan to the Honey Creek, with phosphatic brachiopod shells, both vertical and horizontal trace fossils, and carbonate pelmatozoans, orthid brachiopods, and thick-shelled trilobites present (Donovan, 2000b).

Several different facies are present in the Honey Creek Limestone. In addition to the pelmatozoan grainstones, there are mixed grainstones and quartz sandstones in alternating thin beds that maintain a striking purity of the end members. In areas of mixed composition, there is distinctive wavy bedding with alternating carbonate and siliciclastic beds with small scale cross bedding in each lithology. Rafalowski (1982) described a number of facies. These are shown in Table II. In Blue Creek Canyon, the

Table I

Constituent		Description	Distribution
Siliciclastics	Quartz	grains= silt to medium sand, angular to sub-rounded; overgrowths as cement; beds= lenses with small cross beds, laminae, detritus; inverse relationship between quartz and fauna	Overall decrease upward; but increase into "quartz spike" near top of formation
	Feldspar	mostly K-spar angular to subangular silt to medium sand	similar to quartz
	Rhyolite	sand to boulders; roundess decreases up section; devitrified, altered to iron minerals	size and abundance decreases up section; clasts from Carlton Rhyolite
Allochems	Pelmatozoans	grains= medium sand to pebbles, usually single plates; early syntaxial overgrowths common; late pressure solution features	decreases up section; up to 90% of rock in lower beds
	Trilobites	most are fragmented, though thick shelled; fragments range up to 6 mm; create geopetal porosity	fragments up to 20%; most common in middle of formation
	Brachiopods	disarticulated; up to 4.25 mm; some replacement, geopetal porosity	most common at unconformity with Carlton Rhyolite
	Phosphatic brachiopods	broken fragments up to 4.75 mm; up to 5% abundance	most common in mid formation; along carbonate laminae and pressure solution bands
	Plant fossils, stromatolite, oncolites, algae	stromatolites = red-brown, columnar and bulbous growth; oncolites = alternating carbonate and hematite on fossil fragments, range up to 2 mm	only near unconformity with Carlton Rhyolite; one layer, 127 mm thick, 609 cm across
	Peloids, trace fossils	micite peloids well sorted, 2-3 mm, up to 20% of grains; ovoid; fecal origin; glauconite peloids up to 3 mm, up to 15% of grains; many replaced by calcite; all peloids associated with fossils	micrite peloids in one layer near top of formation; glauconite peloids decrease up formation
Authigens	sparite	abundance ranges 3-56%; up to 1.5 mm; mostly syntaxial overgrowths on pelmatozoans; also blocky, equant, drusy, radiaxial cement	generally decreases up formation
	micrite	occurs as fill of geopetal porosity, burrows, etc.	generally decreases up formation
	dolomite - ankerite	1) zoned (by iron) single rhombs <5% of rock; 2) sparry mosaics that comprise up to 70% of rock	present in lowermost part of formation
	iron minerals	glauconite = peloids; hematite = trace amounts as grain coatings, glauconite replacement, void fill; pyrite = trace amounts associated with glauconite	glauconite decreases up formation; hematite also decreases up formation
Sedimentary Features	stylolites	stylolites and pressure solution present; insolubles occur along boundaries	horizontal stylolites in all formation
	voids	formed by shell fragments	abundant throughout formation

facies are interpreted as reflecting two environments: (1) a sheltered coastal environment with mud, stromatolites, and brachiopod shell banks, and (2) an exposed rugged rocky shoreline with rock pedestals, fissures, rounded rhyolite boulders, covered by coarse grained pelmatozoan sand bodies (Rafalowski, 1982). Donovan (2000b) noted

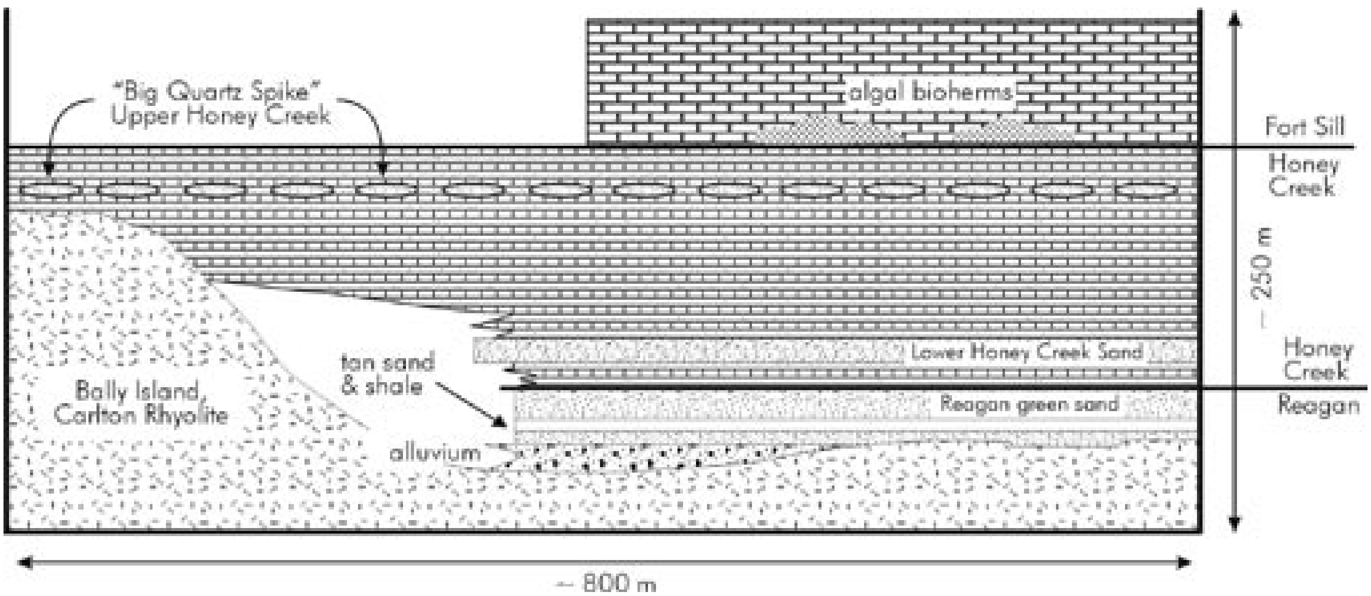

Figure 7. Cross section of the Timbered Hills Group at Bally's Island in the Slick Hills. See Figure 5 for location. Modified from Donovan and Burcheit (2000).

the presence of lime mudstone, bafflestones, sponges, algae, pelmatozoan holdfasts, ferruginous stromatolites, and glauconite hardgrounds in the lee of rhyolite islands (Donovan, 2000b).

McElmoyl and Donovan (2000) identify and describe three informal members: a "lower," an "upper," and a "red limestone" member (Figure 8). The "lower" member is usually much thinner than the "upper" and is composed of light gray pelmatozoan grainstones. Significant amounts of quartz, glauconite, and angular rhyolite grains are also present. Fossils in the "lower" member are broken and abraded. The grains are cemented by syntaxial overgrowths of calcite. Many bedding boundaries are stylolitic; during diagenesis, pressure solution dissolved carbonate against thin quartz sand beds. Cross beds are common and range between 2 and 10 cm (1–4 in) thick. The base of this member contains significant diagenetic oxidized ankerite. Donovan and McElmoyl (2000) showed that the three members could be grouped by end members of sparite, mud, and detritus. Sparite increases in the "red limestone"

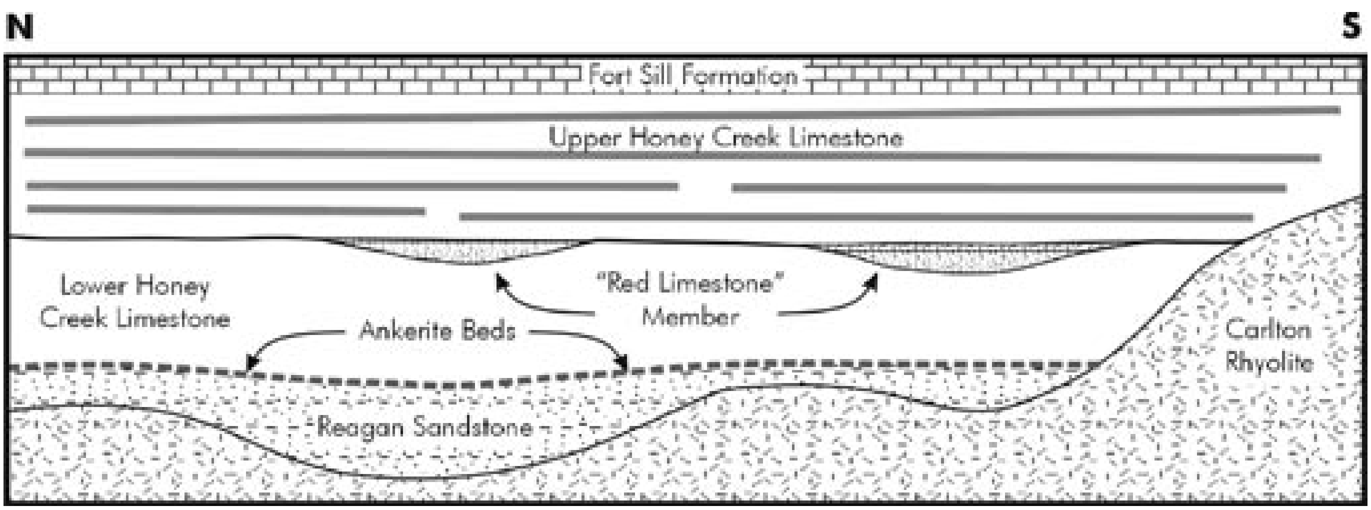

Figure 8. Cartoon cross section of the Timbered Hills Group modified from Donovan and McElmoyl (2000). The "grand cycle" unconformity lies between the "upper" and "lower" Honey Creek Limestone members and beneath the "red limestone" member.

Table II

Facies	Description	Interpretation
Facies A - basal breccia	50% angular, well sorted, devitrified rhyolite (average 3.75 mm); 28% micrite; 20% spar cement with some iron oxide	Initial transgression, erosion by wave action, rapid cementation.
Facies B1 - washed mechanical bafflestone	25% vertical disarticulated brachiopod shells; 20% micrite; 52% radiaxial carbonate cement	shell bank under sufficient wave energy to remove mud
Facies B2 - filled mechanical bafflestone	30% vertical brachiopod valves; 50% micrite; 10% equant spar cement; minor sand and glauconite	same as B1, but less energy, possibly from deeper water
Facies B3 - horizontally packed brachiopod packstone	32% horizontal brachiopod valves; 10% vfg angular sand; 46% micrite; 7% euhedral spar cement; minor glauconite	same as B1 & B2, but below zone of breaking waves. B1, B2, and B3 represent shell bank deposited by waves and currents in fissures of Carlton
Facies C - mudstone	30% quartz, feldspar, glauconite, rhyolite; 10% biogenic fragments; 60% lime mud with stromatolites and oncolites	shallow, quiet water conditions
Facies D - grainstone	90% pelmatozoans with overgrowths up to 1 cm; 10% quartz and feldspar grains; medium-scale cross beds	shoals migrated over lower facies as water deepened; these facies formed in sheltered coastline before covered by grainstones
Facies E - fissure fill	35% vertical brachiopods with hematite rinds; 28% quartz, feldspar, rhyolite, pelmatozoan grains (rhyolite to boulder size); 5% micrite; 6% hematite; 23% anhedral spar cement	debris filling fissures of rocky shoreline
Facies F - medium-scale cross bedded pelmatazoan grainstone	88% pelmatozoan plates with overgrowths up to 1 cm; 10% quartz; 5% micrite	migrating pelmatozoan sand shoals gradually cover rocky coast with fissures filled with rhyolite boulders and fossil debris
Bally Mountain Facies - unconformity cover	30% angular rhyolite clasts up to 4 cm; 15% cg pelmatozoan fragments; minor quartz; 40% anhedral spar cement	initial deposition over Carlton Rhyolite

and "upper" members, as does quartz. In outcrops of the Slick Hills, the "lower" Honey Creek ranges up to 10 m (33 ft) thick; the variations appear to be due to compaction against Reagan or onlap on rhyolite islands.

The upper and lower members are separated by what uniformitarians call a major disconformity, although evidence of physical erosion is not present in all outcrops. The "red limestone," a bioclastic limestone, occurs in lenses beneath the disconformity. The breccia and the disconformity are related to a regional regression that interrupted the Franconian transgression (Donovan and Burcheit, 2000). The "red limestone" member (McElmoyl and Donovan, 2000) is a pink to maroon colored, poorly-sorted, fossiliferous packstone with abundant angular rhyolite pebbles and cobbles up to 10 cm (4 in) in diameter. It erosionally overlies the "lower" member, ranges up to 3 m (10 ft) thick, but cannot be traced throughout the outcrop area. Where the "upper" member overlies the "lower" one, "Contact with the underlying beds is sharp. We have not seen unambiguous evidence of erosion, and no basal conglomerate occurs." (Donovan et al., 2000, p. 42). Its red color is caused by abundant disseminated hematite. The fossils are similar to those of the "lower" Honey Creek, but are less abraded and broken.

The "upper" member is a calcareous quartzarenite with alternating beds of quartz sand and bioclastic grainstone. The composition of the individual layers varies from 90% quartz and 10% bioclasts to 80% bioclasts and 20% quartz. A distinct wavy bedding results from the diagenetic alteration of interbedded sands and carbonates. The small to medium scale cross beds range between 2 and 10 cm (<1–4 in) thick and are common. Some beds in the upper member weather to a distinctive honeycomb pattern from the dissolution of shell hash. The sands are fine-grained and composed of ~70% quartz, 15% peloidal glauconite, fresh feldspar, and minor phosphatic fossil fragments. The carbonates are pelmatozoan grainstones (up to 5 mm), with subordinate fossil fragments and glauconite peloids. These two lithologies are interlaminated down to a millimeter scale. Both have parallel laminae and small trough cross beds up to ~8 cm (3 in) high. The carbonate portion often shows no internal structure; it is masked by horizontal traces and differential compaction due to early calcite cementation of the grainstones, forming rigid plates against compaction. This bedding is interpreted as having formed in an environment with insufficient energy to mix the fine siliciclastics and coarser carbonate sands. "The coarse-grained fragments of pelmatozoans appear to have responded as a discrete grain population hydraulically partitioned from the finer siliciclastics." (Donovan et al., 2000, p. 44).

Donovan et al. (2000) described the "upper" member of the Honey Creek at Bally Mountain (Figure 7). At this location, the formation is 45 m (146 ft) thick and overlies the "lower" member with a distinct bedding contact, but there is no basal conglomerate or evidence of erosion. The basal bed of the upper member is a tan, fine-grained, well-sorted, parallel laminated to cross-bedded quartz sandstone that forms a distinctive ledge that can be traced throughout the area. The succeeding beds include thin alternating layers of quartz and bioclastic sandstone. The percentage of carbonate gradually increases up the first two thirds of the member, then a persistent 1.2 m (4 ft)-thick, tan quartz sandstone with bimodal cross beds, parallel laminations, and abundant angular rhyolite pebbles interrupts the trend. Between that bed and almost the top of the member, the percentages of quartz and carbonate are about equal; then near the top, the percentage of carbonate increases to about 85%. Within this section, there is a 4 m (13 ft) section with a dramatic increase in quartz grains up to granule size called the "Big Quartz Spike." The spike includes quartz, feldspar, and granophyre in a bimodal grain distribution, and it is interpreted by uniformitarians as erosion from the Wichita granites from tectonic rejuvenation. At Bally Island, the top of the Honey Creek is marked by a very visible, one inch thick, purple lime mud hardground, present all over the area and associated with disseminated hematite, glauconite, and phosphate. It forms a growth platform for algae and pelmatozoans.

Diagenesis, or processes affecting the Honey Creek after its deposition, can be deduced by identifying secondary minerals and post-depositional physical features. Radiaxial fibrous cement and syntaxial overgrowths on pelmatozoan parts occurred early, even synsedimentary. The overgrowths are thought to represent a freshwater environment saturated with calcium carbonate (Rafalowski, 1982). Cathodoluminescence patterns show rapid alteration of cement patterns, suggesting rapidly varying water chemistry, as would be predicted in the Flood model. Ankerite, reflecting the continued presence of iron in the sediments, occurs as both a replacement mineral and cement. It is both coarse grained and xenotopic. "In general, the abundance of ankerite must reflect the widespread availability of iron in the diagenetic environment." (Donovan et al., 2000, p. 43) Hematite grain coatings and pore fills occur and are also thought to be early. Sparite formed later, infilling remaining voids. Not unexpectedly, the spar tends to be iron-rich. Silica overgrowths on quartz grains occur in the siliciclastic layers. Glauconite occurs as pellets and pore filling cement.

> Pore filling glauconite is thought to be syndepositional in the Honey Creek Formation as evidenced by later syntaxial overgrowths on pelmatozoan grains with pores filled with glauconite. (Rafalowski, 1982, p. 71).

During diagenesis, grain replacement was also common. Rhyolite devitrification formed silica, hematite, and clay. Calcite replaced quartz, feldspar, and glauconite throughout the formation. Dolomite formed as scattered rhombs and as mosaics of baroque, ferroan dolomite; both found near the Reagan contact, and both late forming. Silica replacement occurred only at the Honey Creek – Carlton contact, where carbonate stromatolite laminae were replaced, resulting in alternating laminae of silica and hematite. Pressure solution after burial led to the formation of stylolites, especially along the contacts of carbonate and quartz beds.

The upper boundary of the Honey Creek Formation (with the Fort Sill Formation of the Arbuckle Group) is defined lithologically as the first limestone with a large mud component. The basal Fort Sill appears as light gray beds of the "tombstone" lithology that is characteristic of Arbuckle Group

> The choice of boundary would seem to be somewhat arbitrary, as the change from "typical" Honey Creek to "typical" Fort Sill takes place over a thickness of 25 m. In practice, the choice can be surprisingly exact. For example, a 2-cm-thick hardground chosen as the boundary during the course of logging a single section on Bally Mountain can be traced along the entire width of outcrop—about 800 m. (Donovan, 2000b, p. 51).

The Southern Oklahoma Archipelago

Interpretation of the deposition of the Timbered Hills Group must include the role of island-forming basement

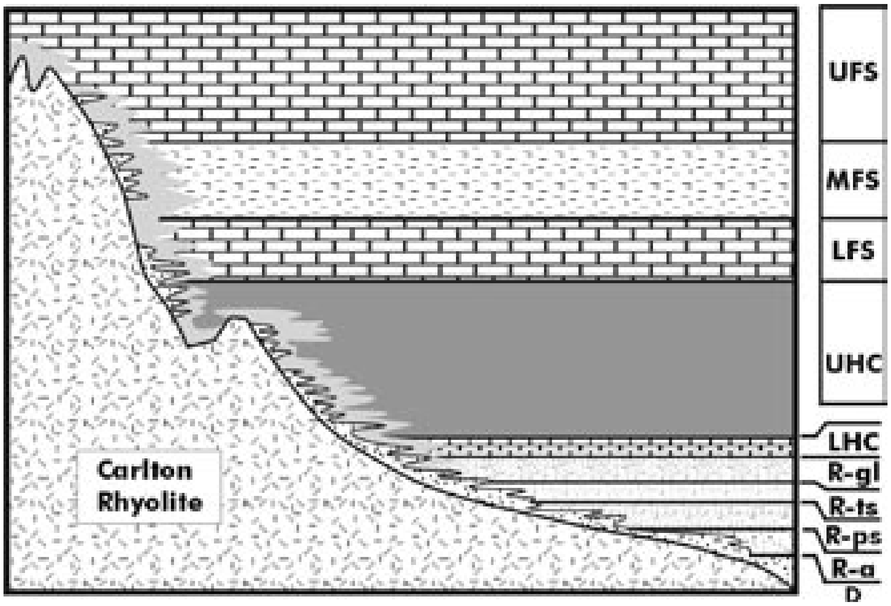

Figure 9. Cartoon cross section of the stratigraphic section onlapping a rhyolite island. Note conglomerate/breccia facies adjacent to the island. Gray shaded areas indicate facies associated with islands. D = basement debris, Ra = Reagan alluvium, Rps = purple Reagan sandstone, Rts = tan Reagan sandstone, Rgl = Reagan greensand, LHC = Lower Honey Creek, UHC = Upper Honey Creek, LFS = Lower Fort Sill Formation, MFS = Middle Fort Sill Formation, UFS = Upper Fort Sill Formation. Modified from Donovan and Burcheit (2000).

topography during the inundation of Oklahoma. North of the SOA, rugged topography with relief up to 200 m (650 ft) known as the "Tulsa Mountains" remained uncovered until covered by Arbuckle Group sediments (Figure 4), but these are not preserved in outcrop. Six islands are exposed, however, in the Slick Hills in Kiowa, Caddo, and Comanche Counties, on the northeast side of the SOA (c.f. Figure 5) along a linear trend of some 24 km (15 mi). Both the Carlton Rhyolite and the overlying sediments are exposed on the islands that have been called the "southern Oklahoma archipelago" (Donovan and Stephenson, 1991). The maximum relief along that unconformity is 300 m (1000 ft). Bally Island is located the farthest inland, to the northwest, and while Richard's Spur Island is located the closest to the ancient shoreline, it was the last covered. Most of the islands had slopes of 10° or less and remained exposed until covered by the Fort Sill Formation of the Arbuckle Group (Figure 9). At Bally Mountain, the Carlton dips 74° NE, while the overlying sediments dip 50°, suggesting a pre-Reagan dip. The two northernmost islands are Bally Island and Ring Top Island, covered by Cambrian sediments, then Permian conglomerates.

The islands influenced facies distribution in both the Reagan and the Honey Creek. Facies distinctively associated with the lee sides of islands include carbonate mud accumulations with fossiliferous mud banks, brachiopod buildups, and ferruginous stromatolites. Outcrops demonstrate that the windward sides of islands had shorelines of coarse grainstone deposits (Donovan and Stephenson, 1991). They described distinct facies at Richard's Spur Island. The island facies are restricted in outcrop and their exposure is limited. Richards's Spur Island extends upward into the Fort Sill Formation. The island shoreline facies is characterized by rich, diverse fossil contents, thin beds (usually < 1 in), hardgrounds, and evidence of reworking. Facies include:

(1) rhyolite breccia with broken shells and clasts, cemented by drusy sparite, and found adjacent to the basement (interpreted as a beach gravel);

(2) pelmatozoan-rich (>80%) grainstone with fragments of trilobites, brachiopods, lime mud intraclasts, quartz silt and glauconite peloids, all cemented by syntaxial overgrowths of calcite (interpreted as wave-washed sand shoals);

(3) poorly-sorted pelmatozoan rich packstones and wackestones (interpreted as below wave base);

(4) poorly-sorted fossiliferous mudstones, with whole brachiopods, sponges, trilobites, pelmatozoans, and algae, intraclasts of lime mud, numerous glauconite-coated hardgrounds (interpreted as protected environment facies);

(5) bafflestones formed by the vertical stacking of brachiopod valves which trapped mud and silt and formed a substrate for pelmatozoans (interpreted as shell banks produced by moderate energy waves); and

(6) ferruginous stromatolites, colored a vivid red by fine grained hematite, forming mats on hardgrounds only 4 cm (1.5 in) thick (interpreted as forming in a protected environment).

Facies associated with these islands demonstrate an upward transition from clastics to carbonates, an upward decrease in size and power of tidal currents, and an upward decrease of basement contribution. Facies distribution was apparently influenced by: (1) sand distribution controlled by island geometry, (2) variability in paleocurrents, and (3) distinct leeward and windward facies, and (4) small contribution of rhyolite fragments to carbonates (Donovan, 2000a).

Donovan et al. (2000) noted that rhyolite conglomerate beds up to 1 m (3 ft) thick with pebbles up to 15 cm (6 in) in diameter are present throughout the Timbered Hills Group. Rhyolite grains in the Reagan are more rounded; grains in the overlying carbonate are angular to subangular, perhaps from carbonate cushioning that minimized abrasion. These were derived from the erosion of the rhyolite basement early on, then from the exposed islands following deposition of the Reagan Formation.

Approximately 275 m (900 ft) in a lateral section of sediments are exposed at Bally Island (Figure 7), where sediments strike N30°W and dip 50° NE. Bally Island was exposed until covered by late Honey Creek beds. The Reagan at Bally Island is thin, but typical in sequence. Its basal unit consists of red beds, including lithic sandstones, conglomerates, and shales composed of poorly sorted rhyolitic debris. These red beds range up to 3 m (10 ft) thick and they appear to be restricted to valleys incised into the rhyolite. Above the redbeds is a tan, pebbly, quartz-rich, well-sorted, coarse-grained sandstone with rhyolite grains and ferruginous ooids. This sand is parallel laminated, laterally continuous, and up to 1 m (3 ft) thick. Ferruginous ooids (up to 15% of the sandstone) are thought to have formed in quiet waters and been transported inshore. Above this sandstone is olive green illitic shale with cross-bedded, tan, medium to coarse grained sand lenses with *Skolithos* ichnofacies. Horizontal ichnofossils occur in the shale. Overlying this unit is a sandstone composed of up to 60% glauconite as abraded, fine to medium grained peloids. This greensand is 4.5–6 m (15–20 ft) thick and persists across the exposure. The sand also contains quartz, phosphatic brachiopods, rhyolite and feldspar. Bipolar cross beds occur in sets up to 1.2 m (4 ft) thick, with the SE ebb flow dominant. The upper green sandstone contains six beds of pebble conglomerate with rhyolite clasts up to 6 inches in diameter. Conglomerate beds persist upward into the Honey Creek (Donovan and Burcheit, 2000).

At Ring Top Island, the relief on the basement rhyolite is only 7.5 m (25 ft), and only the Reagan is exposed. Rhyolite lithics are rare except in lower beds of basal breccia and sandy conglomerate. About 7.5 m (25 ft) of gray and green-gray fine to medium-grained sandstones lap onto Ring Top towards the northeast. The sands appear to pinch out at the island, indicating that it controlled sediment distribution. Glauconite content increases in the fine-grained sands. Sandstones are banked against the island, which appears to have provided little sediment. However, on the southwest side of Ring Top, the situation is quite different. The basal bed is breccia, with boulders of rhyolite up to 80 cm (31.5 in) in a matrix of intensely bioturbated, gray green, fine to medium grained sandstone that rests directly on the basement unconformity. Glauconite is rare in this basal bed, but 1 m up section, it increases to 50% of the sand. Phosphatic brachiopods are also present.

> The impression gained from the section is of rapid inundation of the island by a sea-level rise that led to the development of anoxic conditions, because trace fossils are generally absent in the green sandstones. The only soft-bodied organisms that appear to have survived the flooding event are distinctive crawlers that produced long tracks that were 0.5 in. (1.3 cm) wide. These traces are found on only two surfaces of purple mudstone that were probably clay drapes formed during periods of temporary sediment stability. (Donovan and Burcheit, 2000, p. 35).

About 140 m (450 ft) west of this outcrop, a two-foot-thick tan sandy conglomerate rests directly on the unconformity, showing the rapid lateral facies change away from the island. It consists of rounded rhyolite pebbles up to almost 8 cm (3 in) in a well-sorted quartz matrix with minor rhyolite and glauconite, and is cemented by syntaxial quartz. The basal red beds and ferruginous ooids found at Bally Island are not present at Ring Top (Donovan and Burcheit, 2000).

Uniformitarian Interpretation of Timbered Hills Group

Reagan Sandstone

Uniformitarian explanations of sedimentation emphasize the role of climate over many years. The paleoclimatic setting for the Timbered Hills Group is considered to have been quite different from that of present-day Oklahoma due to purported plate motions. The Cambrian setting for the SOA is placed on the western edge of Laurentia just to the south of the paleoequator with a 70° counterclockwise rotation of from its present orientation (McElmoyl and Donovan, 2000). Therefore, the 20,000,000 years between the Carlton Rhyolite extrusion (ca. 525 Ma) and the initiation of deposition of the Reagan would have been marked by intense weathering of the rhyolite surface (McBee, 1995), as well as erosion and tectonism. It is unclear why this lengthy hiatus failed to produce sedimentary facies prior to the Reagan. The basal Reagan beds are interpreted as alluvial talus and braided stream fill (Donovan, 1986).

Deposited prior to the marine transgression, these sands are found both in channels cut into the rhyolite and atop the basement surface.

Following these changes to the Carlton surface, a late Cambrian (Franconian) transgression began (Figure 2), which signaled a great change in depositional conditions across North America.

> The transgression that began in the Franconian was a world-wide event during which sea levels rose to an unprecedented height by the end of early Ordovician time. (Donovan, 2000b, p. 48.)

The marine transgression progressed slowly inland from the opening Iapetus Ocean to the southeast. Simultaneously, rivers were bringing quartz sand from the craton to the northwest which mixed with locally eroded rhyolite detritus and gradually overwhelmed it, forming the tan to purple, lenticular, cross bedded sandstones interpreted as nearshore and shoreline sands. These were burrowed, forming the *Skolithos* ichnofacies, while horizontal traces formed in shales interbedded with the sands. Paleocurrents in the larger sand bodies are unimodal to the southeast, showing that they formed dominantly from ebb flow off the craton. Thinner beds have bimodal, bipolar, and even herringbone cross bedding, strongly suggesting tidal action. The middle Reagan sands is supposed to reflect current action, showing an increasing percentage of cratonic sand as the Carlton Rhyolite was covered by lower Reagan beds.

The uppermost beds of the Reagan are composed of a spectacular greensand, formed by quartz sand mixed with abundant glauconite peloids. Most workers believe that the shoreline moved northwest, diminishing the terrestrial quartz sand input, giving time for the peloids to form and be evenly distributed. This is supported by glauconite forming at the unconformity between the Honey Creek and rhyolite at islands in the archipelago.

Several lines of evidence are cited in support of slow deposition over several million years (Table III). The presence of pebble conglomerates composed of phosphatic nodules, rhyolite pebbles, and glacuonitized rhyolite pebbles, appear to record substantial reworking and slow-acting chemical processes. The presence of glauconite peloids in the upper Reagan is taken as evidence of the same thing, since the accepted model has glauconite forming from the alteration of fecal pellets. The presence of reactivation surfaces on cross beds is urged as an evidence of slow development. Finally, there is an inverse relationship between *Skolithos* assemblages and glauconite sands taken to mean that some greensand bodies formed in less agitated water. Donovan (2000b) presented other environmental indicators of both the Reagan and Honey Creek formations (Table III).

However, data that are commonly considered diagnostic of time and environment are not necessarily so. For example reactivation surfaces only indicate changes in the physical parameters of dune migration; parameters that obviously are not time dependent.

> Thus, reactivation surfaces seem to be related to fluctuations or changes in the flow mechanism or direction and may not be diagnostic of any environment. (Reineck and Singh, 1980, p. 100).
>
> In computer simulations, Rubin (1987a) formed this type of bounding surface by changes in dune migration direction, dune asymmetry, dune migration speed such that a period of advance is punctuated by a period of erosion, and dune height such that the dune grows by scour of the underlying sediment. (Kocurek, 1996, p. 134).

The presence of pebble conglomerates demonstrates reworking, but reworking can occur without respect to long periods of time. Altered rhyolite pebbles and grains can reflect either a diagenetic change or the preexisting condition, not necessarily a long process. Finally, Froede and Cowart (1994) discussed the failure of trace fossil assemblages to serve as time/environmental indicators.

Honey Creek Limestone

With no erosional boundary between the Reagan and the Honey Creek, the uniformitarian interpretation of the Honey Creek depositional environment must share similarities with that of the Reagan. The lower Honey Creek cross beds show the same bipolar northwest-southeast paleocurrent directions. It also shows a decrease in cratonic clastics and iron and an increasing carbonate influence. The Honey Creek has a simple faunal assemblage of shallow water invertebrates, primarily sessile pelmatozoans that supposedly grew around the rhyolite islands, though not in the deep channels between them. These pelmatozoans were reworked and distributed all over the area by wave action over long ages (Donovan, 1986). The resulting carbonate sands are not lenticular, but appear to have formed from the migration of very small dunes, less than 23 cm (9 in) high. As the dunes accumulated in the straits, the water depth became shallower and the carbonate system became more effective.

Rafalowski (1982) posited a variety of environments for the Honey Creek, ranging from intertidal to offshore marine and from brackish to normal marine salinity, and from low to high energy environments. Stromatolites, oncolites, and algae and radiaxial fibrous cement are thought to indicate low energy; the cross-bedded pelmatozoan sands indicate higher energy. Horizontal burrows and fossils are accepted as indicators of deeper water; since they occur near the top of the formation, they suggest deepening water following the

Table III

Physical Indicator	Probable Physical Cause	Uniformitarian Interpretation	Flood Interpretation
Rhyolite grains decrease from 80–90% in basal Reagan to 0% in Fort Sill	Increasing vertical & lateral distance between source and deposit	Development of regional carbonate platform cuts off clastic source	Same concept, accelerated time
Rhyolite pebbles in Reagan are generally rounded; those in Honey Creek are generally angular	Less time for rounding of pebbles by weathering, and for transport and deposition of pebble	Only basement islands available as source; limited erosion and transport	Rapid erosion and limited transport of pebbles combine with rapid burial of rhyolite sources
Conglomerate pebbles = phosphate nodules, rhyolite pebbles (some glauconitized)	Phosphate probably transported into area, rhyolite derived locally	Evidence of long ages of reworking and slow-acting chemical processes	Phosphate imported from antediluvian ocean; rhyolite eroded and redeposited locally, altered diagenetically later
Quartz in Timbered Hills is mature except for lower Reagan	Quartz derived from cratonic source; mature sand already present	Sand transported by rivers and wind from interior to coast (although unexpected during transgression)	Sheet flooding rapidly brings sand to coast at same time as transgression; sand mixed by marine front
Quartz grain size decreases up; from granules and coarse sand in Reagan to vfg sand and silt in Arbuckle Group	(1) decreasing energy or (2) increasing distance from source of coarser grains	Enlargement of Oklahoma Basin increases distance to source	Rising Flood waters result in longer distance from suitable source to deposit, and fining upward sequence
Biggest change in quartz grain size between "lower" and "upper" Honey Creek	Change in transport energy or source	Major regression (grand cycle) within Honey Creek	As marine front moves rapidly inland, coarser sand trapped there, only fines migrate offshore
Plagioclase found only in lower Reagan	Plagioclase derived from rhyolite	Plagioclase source cut off by burial.	Same concept, accelerated time
Glauconite most abundant in upper Reagan, then decreases through Honey Creek into Fort Sill Formation	Chemical environment forms glauconite in upper Reagan, Honey Creek; dominant in upper Reagan	Alteration of fecal pellets in normal marine waters can produces glauconite, but cannot explain why it decreases with increasing faunal diversity	Glauconite imported from antediluvian offshore; or precipitated rapidly in rare geochemical window
Phosphate trend tracks glauconite; most occurs as broken shells of brachiopods; nodules also present	Similar chemical environment for both glauconite and phosphate	not explained	Unusual chemical environment either from antediluvian ocean or from conjunction with volcanism at SOA
Glauconite peloids comprise up to 60% of upper Reagan sand; peloids are abraded and broken	Fragile peloids only transported short distance	reworking virtually in situ; no explanation for concentration in upper Reagan	Stratigraphic occurrence may mark rare chemical window; or initial migration from antediluvian sea
Hematite cement is present (up to 30%) in lower Reagan in disseminated form, overgrown by silica cement	abundant iron and oxygen	Iron from rhyolite weathering	Iron from late-stage volcanism; high heat flow; oxygen from rainfall
Hematite abundant in the "red limestone" member, in contrast to the upper Reagan, lower and upper Honey Creek.	iron is fixed in an oxidizing environment, probably in shallow water	Regression during Honey Creek exposed rock to subaerial processes	Short, energetic regression not inconsistent with Flood, oxygenated waters of Flood cause iron precipitation
Horizontal ichnofacies are found in fine-grained facies of Timbered Hills Group up into Arbuckle	organisms moving parallel to bedding boundaries	Indicative of deeper water, lower energy	Not environmental indicators; may have formed after burial
Skolithos ichnofacies occurs only in middle Reagan sands	Presence of vertical burrowing organism (such as shrimp)	Skolithos indicates higher energy environment such as beach	Skolithos is poor enviornmental indicator; may represent escape traces of rapidly buried organisms
Inverse relationship between Skolithos ichnofacies and glauconite sands	unknown	Greensands formed in less agitated water conditions; assumes Skolithos indicates higher energy	multiple explanations possible, insufficient data

Table III (continued)

Physical Indicator	Probable Physical Cause	Uniformitarian Interpretation	Flood Interpretation
Broken and abraded pelmatozoans form bulk of the Honey Creek carbonates	source of massive population of pelmatozoans	Pelmatozoans grew in place over long time; indicate shallow, oxygenated waters	Pelmatozoans transported from antediluvian sea and deposited
Broken, abraded shells of thick shelled trilobites in Honey Creek	thick-shelled trilobites present	Mobile benthonic organisms strong enough to withstand agitated water	Evidence of high energy transport; possible winnowing of thin shell types
Calcitic and phosphatic brachiopods; calcitic concentrated near base of Honey Creek, phosphatic throughout	Phosphatic shells indicate high organic activity and nutrient rich waters	Modern brachiopods are benthonic, tolerate range of depth, but not agitated water or low salinities.	Calcite shells may be replacement following deposition; Ca ions concentrated at lower boundary
Stromatolites, oncolite, and algae occur only at the Honey Creek-Carlton unconformity	algae population	Shallow subtidal or low intertidal environments	Antediluvian algal communities transported, deposited in quiet water; short time for growth
Basal Reagan is coarse alluvium; some desposited in channels cut in rhyolite	Erosion into rhyolite, short transport and deposition	Local erosion prior to transgression	Rapid tectonic change in base level cuts channels in rhyolite; rapid erosion and deposition of lower sands in "fresh water" Flood
Reactivation surfaces cut cross beds in Reagan and Honey Creek formations.	Change in current direction or strength during deposition; observed in fluvial and tidal environments	Indicates long time period during deposition of sands	Indicates current changes without respect to time
Silica cement throughout Reagan; postdates hematite	Silica ions present	Silica from rhyolite degradation	Silica possibly from late-stage volcanic fluids; higher heat flow enhances precipitation
Iron ooids in middle Reagan sands, deformed by compaction	Short range transport of ooids from unusual environment; time of compaction sufficient to deform ooids	Ooids formed in nearby quiet environment, then transported and deposited	Ooids from pre-Flood offshore source or formed rapidly at shoreline due to rare chemical window
Timbered Hill thickness is relatively uniform over entire state	Depositional processes operating in similar fashion over large scale	Greater variety in thickness due to variety of environments expected	Expect similar processes operating over regional area
Boundary between Reagan and Honey Creek is first appearance of carbonate - diagenetic ankerite	No carbonate formed prior to Honey Creek; ankerite from mixing of HC carbonate and Reagan iron	Change of environment to marine carbonate; ankerite from groundwater circulation	Deposition is a continuous process; boundary marks first appearance of offshore carbonate constituents
Very little detrital clay in the Honey Creek in contrast to the Reagan	clay not deposited, or winnowed after deposition	Increasing distance from clastic source, hard to explain quartz transport	High energy environment keeps clay in suspension
Rhyolite islands show different facies from one side to the other	Islands block strong currents	Lee side protected in tidal marine environment	Lee side provides local lower energy, different hydraulic environment
Bimodal NW-SE current during Reagan deposition; ebb flow dominant	Bimodal flow	Shallow marine setting; currents reflect tidal influences	Currents reflect interplay of "fresh-water" floodwater and marine front
Quartz sand spike in upper Honey Creek	Quartz sand source in upper Honey Creek	Regression in middle of Honey Creek allowed transport of sand from then distant shoreline by rivers and wind	Marks spike of "fresh water" flooding or current winnowing
Honey Creek = interbeds of quartz sandstone and pelmatozoan clasts	Source of both types of sediment and means to mix them	Low energy mixing of sand from regression and in situ pelmatozoans	Interbeds caused by hydraulic sorting or quartz and carbonate
Small-medium scale cross beds, occasional herringbone cross beds, mostly in lower Honey Creek	low flow regime	migration of bars and shoals in shallow marine setting; herringbone cross beds indicate tidal influence	Energy decreases as transgression migrates inland and water depth increases

transgression. The presence of glauconite grains is expected because of the supply of ferric oxide on the craton.

The three most important factors in the uniformitarian interpretation of the Honey Creek are (1) the paleogeography, (2) pulses in the ongoing transgression, and (3) the tectonic development of SOA (McElmoyl and Donovan, 2000). Rhyolite islands of the southern Oklahoma archipelago explain the presence of rhyolite clasts persisting well up into the formation. They also caused the development of unusual, restricted carbonate facies on the protected sides of the islands. Thickness variations were caused by differential compaction on the islands. Lateral variations in the ratio of quartz to carbonate are explained by the presence of pelmatozoan colonies around the islands and quartz sand in the tidally dominated channels between the islands. Faunal variations are explained by ecological partitioning (Donovan, 2000a).

As the Franconian transgression began to mantle the basement with sediment of the Reagan Formation, increasingly longer transport distances for cratonic clastics developed.

> Whereas all the detritus of the initial deposits of the Reagan appears to be of local origin, the upper part of the Reagan, as well as the entire Honey Creek, contains abundant detrital quartz. Although some quartz may have been derived from the Carlton Rhyolite (which contains a small percentage of quartz phenocrysts), most must be of distal origin and was presumably incorporated into the sediments as the transgression advanced across the craton. (McElmoyl and Donovan, 2000, p. 73).

McElmoyl and Donovan (2000) argued for the existence of a "grand cycle" (regression-transgression) within the Honey Creek formation. There is some evidence of erosion at the base of the "red limestone" member and it may have been deposited as detritus created by erosion during a regression. Donovan et al. (2000) state that there is an easily recognized field break in the Honey Creek; in some places, a slight angular unconformity, in others, a disconformity. In other words, like the "red limestone," the erosion appears to have not been consistent throughout the Honey Creek. This regression is also used to explain changes in water chemistry between the "lower" Honey Creek member and the "red limestone" member. The "red limestone" member was apparently deposited in a protected environment because of abundant mud, diverse fauna, less abraded fauna, and abundant rhyolite clasts. The presence of islands means that the detritus that formed the "red limestone" member could have come from older, but topographically higher beds. It is not clear whether or not the "red limestone" member was originally deposited as discontinuous lenses, but there appears to be little evidence of a sharp erosive boundary between the "upper" and "lower" members where the "red limestone" member is not present. (Donovan et al., 2000).

However, quartz sand in the "upper" Honey Creek had to have originated from a shoreline that was rapidly moving inland relative to the outcrop area. One of the reasons that a regressive-transgressive pulse is posited as having occurred during the middle of the Honey Creek is to provide a means by which sand was transported over the newly deposited sediment by rivers and wind. However, the interbedded nature of the sand throughout most of the Honey Creek defies that explanation. If a transgressive-regressive cycle occurred, the sand should occur as a thick transgressive lag above the "red limestone" member, rather than thin layers interbedded with carbonate throughout most of the member.

The unusual occurrence of interbedded sand and bioclasts in discreet alternating beds is thought to have resulted from energy levels sufficient to ripple the sea floor (forming cross beds) but too low to mix the quartz and carbonate sediments. Trace fossils in the "upper" Honey Creek are cited as support for quiet conditions (Rafalowski, 1982). McElmoyl and Donovan (2000) see a progression from the tidally influenced sands of the upper Reagan beds to the addition of a carbonate component to form the "lower" Honey Creek. They posit a widespread eustatic pulse led to the deposition of the "red limestone" member and continued regression allowed the migration of quartz sand into the area. Renewed transgression then mixed the quartz sand and carbonate bioclasts into alternating beds, forming the "upper" Honey Creek. They propose a eustatic, rather than tectonic, regression because of its correlation with other locales and the absence of any clear evidence of tectonic motion at that time. The rapid subsidence of the SOA did not begin until Arbuckle time.

Smaller cross beds in the Honey Creek (compared to the Reagan) indicate less water energy, or tidal power. Donovan (2000b) stated that the lower energy resulted from a spreading transgression across the shallow continental surface, since a broader platform would decrease the energy. In conjunction with the proposed decrease in tidal energy is a vertically upward decrease in tractive power and sorting. Ultimately, the decrease in energy resulted in the accumulation of lime mud and the proliferation of lime-mud-producing organisms. The base of the Arbuckle Group is marked by carbonate mud which implies a decrease in tidal energy, expansion of the carbonate platform, and increased algal growth.

During the lower Paleozoic transgression, the SOA was transformed from a locus of tectonic and igneous activity to a profound depocenter for the Oklahoma Basin (Figure

10). The boundaries of the SOA are partly defined by the isopach of lower Paleozoic sediments; the depocenter contains thicknesses of units up to four times their thickness outside the rift. However, uniformitarians consider the initial subsidence rates during Timbered Hills time to be slow, not speeding up until Arbuckle deposition (McElmoyl and Donovan, 2000). If the tectonism in the SOA was continuous, however, the "subsidence rate" of the Timbered Hills Group only indicates how quickly it was deposited.

It is worth noting that the presence of pelmatozoan plates does not require their *in situ* growth during Honey Creek time. They could have been transported and deposited during a short time. It is also possible that even stromatolites, oncolites, and associated mud could have been transported into the area and deposited in quiet areas in the lee of the rhyolite islands. As already noted, trace fossils are not necessarily diagnostic of particular environments. Other time indicators, such as glauconite grains depend on assumptions rather than field evidence. Rafalowski (1982, p. 84) admits this:

> In addition to iron and other necessary ions, glauconite requires stable Eh conditions and considerable time to form. Many of the rocks of the Honey Creek Formation do not appear to have formed in such an environment. Considerable reworking of grains is implicit. The original environment of formation may have been distal offshore marine.

Discussion

Almost two centuries of research within the uniformitarian paradigm have created a fabric of stratigraphic analysis where individual threads of data are interwoven with uniformitarian stories. Replacement of the "standard" interpretations requires both an understanding of the physical rock record, and an ability to discern the difference between legitimate cause and effect reasoning and that tainted by hidden assumptions of extended time and/or modern processes. Table III provides a brief summary of many of these issues as they relate to the Timbered Hills Group. Some of the topics, however, can be extrapolated to other locations, and for that reason are granted a place in this discussion section.

Extent of Basal Sequence

Flood geology and uniformitarian geology differ in their predictions of the scale of sedimentary processes. The former predicts large-scale synchronous deposits, the latter does not. The basic sequence that comprises the Timbered Hills Group (eroded igneous basement to immature sandstone to mixed siliciclastic/carbonate to thick carbonates) in Oklahoma extends far beyond, covering much of the midcontinent of North America. However, uniformitarians cloud this remarkable occurrence with different dates, nomenclature, and an emphasis on small scale lithologic variation, obscuring the forest by concentrating on the veins in the leaves. But positing differences based on small facies changes and fossil zonation cannot hide the true extent of this simple sequence. It exists over much of Texas, Oklahoma, Kansas, Missouri, and Iowa to the author's knowledge, and perhaps it is present to an even greater extent.

> This pattern of facies in which coarse sandstones and conglomerates pass upward into glauconitic sandstones and hence into carbonates is typical of the Reagan Formation *and its equivalents.* (Tsegay, 1983, p. 8, emphasis added)

It is argued that this sequence is merely that expected during a multi-million year transgression. However, strong arguments may be made against this assertion. First, the scale of the transgression alone refutes uniformitarianism. Where today do we see vast areas of continental crust becoming shallow marine environments? Where do we see continent-

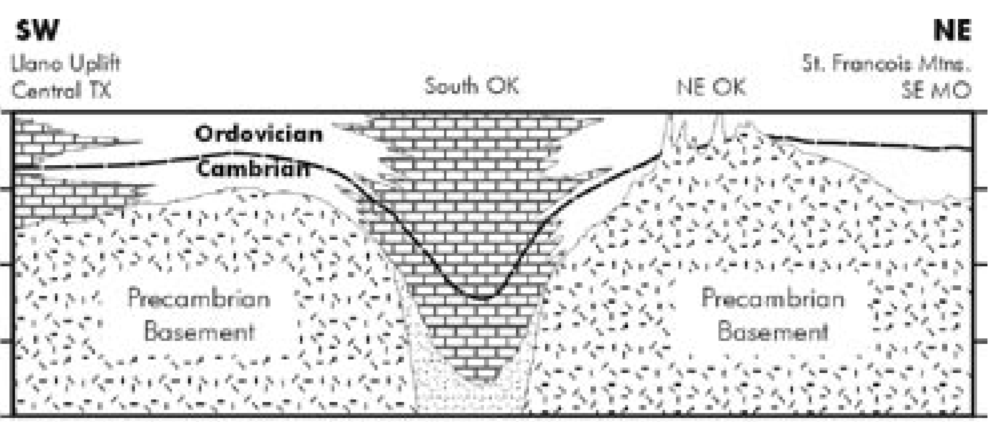

Figure 10. Cross-section of the Southern Oklahoma Aulacogen during "early Ordovician" time, showing development of depocenter. Solid white indicates areas of dolomitization, rather than limestones deposited in depocenter. Note significant vertical exaggeration. Modified from Johnson et al. (1988).

wide transgressions that include the large-scale transport of sand, erosion down into bedrock, large-scale tectonism, and intraplate volcanism? Second, and more telling, hydraulic and chemical parameters of deposition are usually fragile with regard to time. Long periods of time provide ample opportunity for environmental conditions to change. A better explanation of the regional similarity of erosion and deposition would be the wide scale flooding of the entire midcontinent rapidly enough to prevent major changes in the depositional regime from being reflected in the resulting sediments.

In that regard, very specific conditions would be required to produce the sequence observed in the rock record. The occurrence of a thin sheet of sand, particularly one with similar facies, and especially one with unusual widespread, similar facies, speaks to specialized depositional conditions. Both a consistent range of hydraulic energy changing in a consistent manner during deposition and consistent geochemical parameters would be required to produce what is observed. In addition, the burial and preservation of this sand over an equally large area again argues for very rapid processes operating within very narrow chemical and current ranges.

Parameters of Sedimentation

Analysis of the formation of any large sedimentary deposit must include several interrelated parameters: (1) erosion and provenance, (2) subsidence and the creation of accommodation space, (3) transport and deposition, and (4) preservation. These are accomplished under the influences of (1) tectonic motion of the crust, (2) hydraulic energy, and (3) time. Increasing hydraulic energy requires less time; decreasing energy, more time to accomplish the formation of similar thickness of strata. Since Genesis provides the duration of the Flood, we know that the hydraulic (and tectonic) energy levels must have been quite high (Reed et al., 1996).

The Timbered Hills Group supports this paradigm of rapid formation. The pre-sediment tectonism of the SOA indicates almost contemporaneous downwarping, igneous extrusion, erosion, and sedimentation. For example, at Bally Mountain the Carlton Rhyolite dips 74° toward 050° (NE), while the overlying sediments dip 50° toward 060°, a significant pre-sedimentation dip (contrary to the assumption of original horizontality). Donovan and Stephenson (1991) note that the Carlton Rhyolite underwent rapid subsidence and was not elevated above the craton when sedimentation started. The thickness patterns of the Arbuckle Group also reflect subsidence in the SOA. Should we believe that the SOA sank during emplacement of the Carlton Rhyolite, stopped for a long period while the Timbered Hills Group was deposited, and then started sinking again during Arbuckle time?

Erosion was also rapid, creating the unconformity on the basement surface. I believe that erosion of the basement was accomplished primarily by the freshwater Flood; rainfall would have soaked the soil and eroded down to bedrock in short order (Genesis 7:11–12). The amount of rain would probably have resulted in sheet flooding leading to the basement being "swept clean of debris" (Johnson et al., 1988, p. 310) prior to marine transgression. This happened over a continental scale and would therefore have required sheet erosion of continental scale. Uniformitarians explain the basement surface in terms of long ages of erosion. "Not surprisingly, the unconformity beneath the Cambrian sedimentary rocks is exceedingly irregular…" (Donovan and Burcheit, 2000, p. 27). However, the local irregularity can be explained easily within the Flood paradigm by the scale of the regional erosive event; another instance of uniformitarians missing the forest for the trees. Irregularities of even a few hundred meters over an area of thousands of square miles do not appear significant, especially when most of the irregularity occurs in areas of ongoing tectonism and igneous extrusion. The short period of intense rainfall and associated flooding would not have planed the newly-extruded rhyolite, especially since its rapid hardening may have resulted in an irregular surface. Also, current variations that might be envisioned in sheet flooding over thousands of square miles could have produced variations in the depth of erosion. Additionally, Gilbert (1983) concluded that the rhyolites were extruded at high temperatures (950–1000°C). Intense rainfall would have resulted in very rapid cooling, perhaps leading to the fracturing and the creation of an irregular surface. Finally, the sedimentation over the eroded basement would have had to occur quickly to preserve the clean eroded surface, again on a continental scale.

As the outgoing freshwater front met the incoming marine front, the hydraulic energy of the freshwater would have decreased with rising base level. Deposition would have begun as locally eroded sands were laid down, first in depressions in the irregular surface, and then over the entire area. Competing currents from the outgoing freshwater and incoming marine water would have resulted in an area of ebb and flow that uniformitarians have mistaken for tidal action. Quartz sand moved back and forth, and was deposited under increasingly marine influence across a broad front, resulting in the more widespread beds of the middle and upper Reagan. The lack of carbonate mud in the Reagan indicates continuing current strength sufficient to keep that mud in suspension that did not abate until Arbuckle deposition (Figure 11).

Both energy and provenance contributed to the final sediment sequence. I believe that hydraulic energy peaked during the freshwater erosion of the basement, then declined as the marine front moved landward. Erosional sheet flow was replaced by a zone of mixing resulting in ebb and flow currents. As the marine front passed, wave action became dominant and hydraulic energy probably decreased farther with increasing water depth. Simultaneously, the siliciclastic content transported seaward was deposited first as the Reagan Formation, then was mixed with carbonate debris transported inland by the marine front. Irregularities in the surface allowed for the local precipitation of clays in protected areas. Finally, the continental source of sediment was cut off, and almost all of the sediment deposited was carbonate. This point is marked by the rapid transition to almost pure carbonates above the quartz spike in the upper Honey Creek. Subsequently, decreasing energy finally allowed the settling of carbonate muds in the Arbuckle Group.

Provenance of Quartz Sand

What is the provenance of the mature quartz sand found throughout the Timbered Hills Group? How far was it transported across the craton? How was it transported to the Honey Creek shoreline after large areas of the local basement had been covered? These questions have a broader application. Megaregional carbonate platforms covered much of North America during the "lower Paleozoic." However, interspersed within this thick carbonate sequence are deposits of mature quartz sands. The question is how these sands could be transported across hundreds of miles of low energy, shallow water carbonate deposits in a coherent mass and be deposited as such. "The major problem associated with the quartz is that of provenance." (Tsegay, 1983, p. 62).

This process began almost immediately in the sedimentary record. Donovan et al. (2000) noted that the provenance of the upper Honey Creek (finer-grained, well-sorted quartz) was different from that of the Reagan and lower Honey Creek (coarser sediment). Since the source does not appear local, they interpreted the source of the upper Honey Creek as being from eolian dunes transported seaward during the mid-Honey Creek regression.

> Whereas all the detritus of the initial deposits of the Reagan appears to be of local origin, the upper part of the Reagan, as well as the entire Honey Creek, contains abundant detrital quartz. Although some quartz may have been derived from the Carlton Rhyolite (which contains a small percentage of quartz phenocrysts), most must be of distal origin and was presumably incorporated into the sediments as the transgression advanced across the craton (McElmoyl and Donovan, 2000, p. 73).

However, if volumes of quartz sand had been deposited on the shelf during regressive lowstand by rivers and wind-blown dunes, then why would the sand have been interbedded in the upper Honey Creek to nearly the top of the formation? Why would it have not formed a basal transgressive sand at the base of the Upper Honey Creek member that used all of the quartz before being buried by carbonate? After all, the Honey Creek deposition should have occupied at least a million years, and a continual, but irregular source of small amounts of

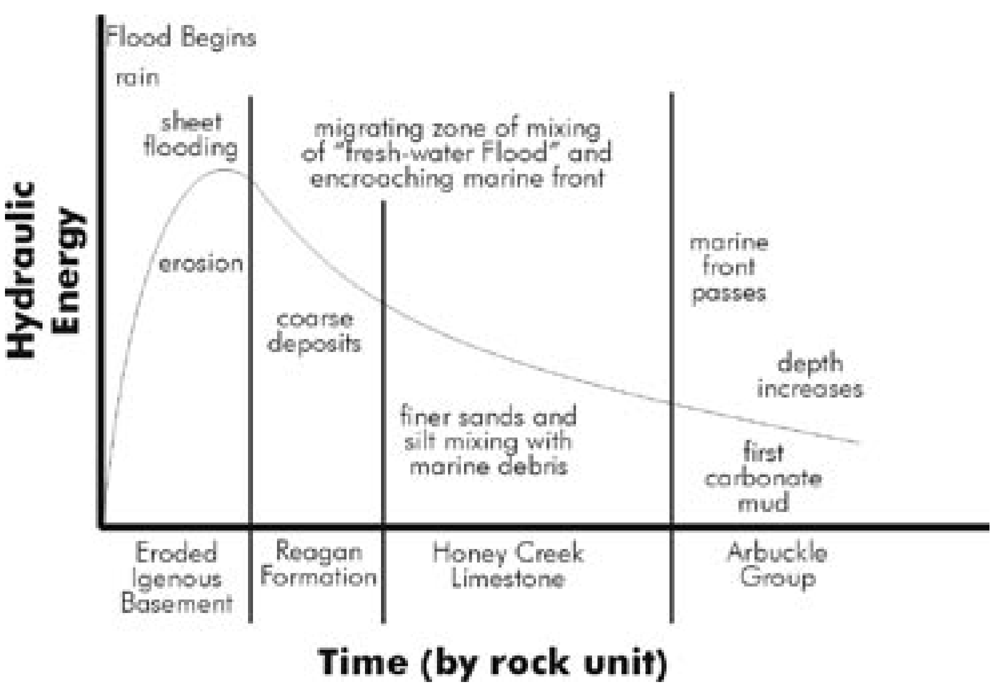

Figure 11. A paleohydraulic curve of the early Flood shows the expected sequence of erosion, followed by deposition of the Timbered Hills Group, as energy increased rapidly at the onset of the Flood and then decreased as the marine front moved across Oklahoma.

sand would have been required. The physical evidence rather demonstrates a continuous source of clean quartz sand that was hydraulically intermixed with the grainstones of the Honey Creek until the source or the pathway of the quartz dried up prior to Arbuckle deposition. Furthermore, long periods of time would have allowed the introduction of a significant silt and clay component, transported by wind (Froede, 2003).

Most of the uniformitarian authors speculated that the source of the quartz sand was the Canadian Shield, but were very limited on the specifics of how it was transported all the way across a continent, and how it was distributed evenly throughout the Honey Creek as discrete beds, rather than simply intermixed with the carbonate. None of these authors performed mineralogical or chemical analyses to verify provenance. I do not argue with the possibility of the provenance being the Shield, but would add another possibility. The northern midcontinent contains the erosional remnants of mature orthoquartzites (i.e., Baraboo, Sioux, etc.). If these were once a widespread, unified quartz sand body, then erosion by freshwater flooding during the early stages of the Flood might have transported a sufficient supply of very mature monocrystalline quartz to the continental margins, leaving the few indurated remnants that are present today. Mixing with eroded granitic basement would have provided the small percentages of feldspar and other minerals found in the Timbered Hills Group. What else besides the Flood could erode material from the Shield or upper Midcontinent, transport it across a continent and deposit it as we see it?

Origin of interbedded clastics and carbonates in the Honey Creek Limestone

In areas of mixed composition, there is a distinctive wavy bedding with alternating carbonate and siliciclastic beds with small scale cross bedding in each lithology.

> Evidently, the current power available was insufficient to mix the two varieties of sand. In part, this may have been due to the discrepancy in size of the particles—very coarse sand to granule-sized carbonate grains, as opposed to very fine to fine-sand siliciclastics. In addition the carbonates appear to have cemented rapidly… (Donovan, 2000b, pp. 49–50).

This uniformitarian interpretation assumes a constant, relatively equal, regularly alternating supply of quartz and carbonate sands. But a review of the uniformitarian paleoenvironment shows that such an arrangement is not possible. By Honey Creek time, the basement was almost completely covered by carbonate deposits and there is no physical evidence (e.g., channels sand facies) of large fluvial systems importing sand onto the carbonate shelf. The section above explained the dilemma from the standpoint of the source of the sand, but the nature of the sand-carbonate mixing is also worthy of comment.

Sand and carbonate grains are not completely segregated, nor are they completely mixed. Instead, they are discretely interbedded in thin alternating beds of each component. If it is true that the current power was insufficient to mix the two populations, then how was that same low current power sufficient to distribute the cratonic sands widely across the entire shelf area at specific times (the sand interbeds), yet not at others (the carbonate interbeds)? And why, given the time involved in the uniformitarian story, were not the two populations intermixed by bioturbation?

Uniformitarians are limited by their "stratigraphic" approach to sedimentology. One benefit of Flood geology is an emphasis (unfortunately not applied consistently enough) on the hydraulic framework of sedimentary deposits (Berthault, 1994, 2000). The interesting nature of the carbonate-quartz interbeds provides a good example of the superiority of the Flood framework. Although the relative density of quartz and limestone is similar (Allen, 2001), the disparate grain size and shape between the quartz and bioclasts (echinoderm plates) provides a basis for hydraulic sorting within the mixing zone of fresh and marine water which was migrating inland across the shelf. Quartz sand was transported from the cratonic interior to the marine front in the widespread freshwater sheet rushing to meet the marine transgression, not in narrow, restricted river channels. Pelmatozoans were being washed inland with the marine front and the two-grain populations were sorted into the interbeds of the Honey Creek that we observe today.

Persistence of Rhyolite Islands

According to the uniformitarian explanation of the southern Oklahoma region, the end of igneous activity (Carlton Rhyolite and late intrusive dikes) occurred ~525 Ma. The base of the Dresbachian (Upper Cambrian) is ~505 Ma, and the base of the Ordovician is ~495 Ma. Thus the three stages of the Upper Cambrian (Dresbachian, Franconian, Trempealaunean occupied ~10,000,000 years. If the time interval of all three is assumed equal, then the onset of Reagan deposition was ~501 Ma, and the Timbered Hills Group would have been deposited over a period of 1,000,000 to 2,000,0000 years. (Figure 2).

This period of time raises the question of the endurance of the rhyolite islands of the southern Oklahoma archipelago, which lasted until early Fort Sill Formation deposition. Would these rocky islands resist erosion for that length of time?

> Rocky marine shorelines are rarely preserved in the geological record… In general, most major marine uncon-

> formities are planar surfaces. Rocky, island girt shorelines characterized by irregular relief generally involve rocks that are resistant to weathering… Preservation of this relief generally seems to involve rapid rates of subsidence… or rapid transgression, or a combination of the two. (Donovan, 2000a, p. 19).

The two northernmost islands are Bally Mountain and Ring Top, both visible in outcrop in the Slick Hills. They are covered by Cambrian sediments, then Permian conglomerates. The Timbered Hills Group laps onto Bally Island. This onlap is interpreted as a dramatic hiatus, but in reality could have occurred in a short time as the sediments were deposited on the preexisting irregularity in the surface. This question can be extended to the wider area. The Franconian transgression occurred across an irregular basement surface. Its irregularities are exposed in the St. Francis Mountains, the Arbuckles, and in the subsurface "Tulsa Mountains" of southeastern Oklahoma. How could this widespread Precambrian landscape remain both stripped clean of any surface cover and yet topographically irregular for hundreds of millions of years? Erosion of the basement would have occurred during that time, erasing the topography while creating a sediment and soil cover that does not exist. Only a high-energy hydraulic event could have stripped the surface cover and eroded down into bedrock, and only a short-lived, high-energy event would have left the surface irregularities in the "clean swept" surface.

Geochemistry of the Timbered Hills Group

The Timbered Hills Group represents an unusual geochemical environment, especially with respect to iron. A variety of interesting iron minerals and sediments occur throughout the section. Iron is seen in ankerite, hematite, and iron-rich illite cements, and replacement minerals such as ankerite, siderite, glauconite, and pyrite, and intraformational grains such as ferruginous ooids and glauconitic peloids (Figure 12). Hematite occurs as disseminated cement in the lower Reagan beds, while glauconite with Fe^{2+} and Fe^{3+} dominate the upper. Ferruginous ooids are present in the middle Reagan beds.

> It is clear that the Reagan Sandstone is characterized by an unusually high amount of iron. (Tsegay, 1983, p. 55).

Furthermore,

> This iron is manifest in both valency states, as hematite cements, ferruginous ooids, a variety of forms of glauconite, iron-fixing bacterial stromatolites, ferroan-calcite and ankerite cements, and the widespread replacement of calcite by ankerite. (Donovan et al., 2000, p. 40).

There are several questions to be answered regarding this phenomenon. These include: (1) the source of the iron, (2) abundant hematite in the Reagan, (3) the presence ferruginous ooids in the middle Reagan, and (4) the origin of glauconite in the upper Reagan and Honey Creek, as well as the distribution of iron minerals upward through the section.

Uniformitarians answer the first question by pointing to weathering and erosion of the rhyolite (although I am not aware that the iron in the Timbered Hills Group is restricted to those locations overlying rhyolite). Was the iron derived from almost 20,000,000 years of weathering of the Carlton Rhyolite, which contains up to 8% iron? If so, would not the iron have been dispersed down to the ancient sea during

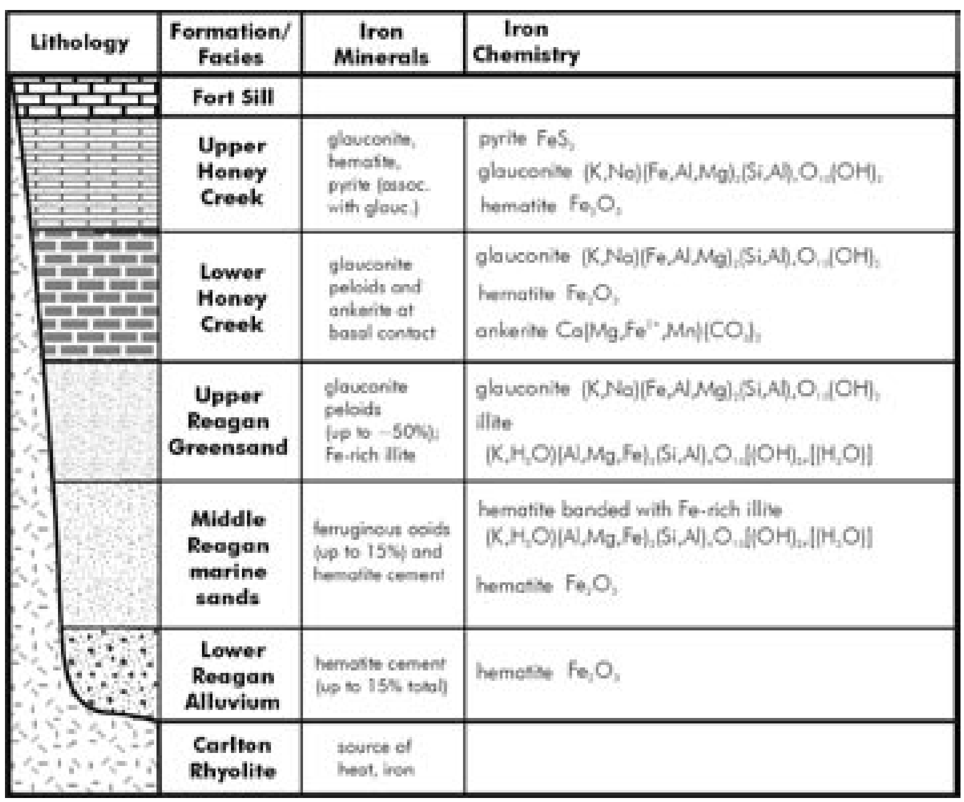

Figure 12. Iron mineralogy and chemistry of the Timbered Hills Group.

that time? Another possibility is that the iron was derived from the essentially synchronous volcanism occurring in the SOA as sedimentation initiated. In that case, iron would not be limited to crystalline rock, but might be present in outgassing water that would mix with the rain and/or marine floodwaters and be spread across a wide area. Certainly such a scenario would involve fluctuations in water chemistry and temperature not seen in modern environments. High amounts of dissolved or colloidal iron would provide a reservoir for the abundant glauconite and ooids.

Hematite is abundant in the lower Reagan beds, virtually absent in the rest of the Reagan, and is present throughout the Honey Creek. Hematite is associated with oxidizing environments; its presence in sediments deposited by the "freshwater" Flood is not then unexpected. Hematite occurs as disseminated particles that combine with silica to cement those strata. It may well have been rapidly precipitated from iron rich pore fluids as the fresh, cool rainwater changed the temperature and Eh-pH environment quickly. Even uniformitarians recognize that the distribution of hematite must have been followed quickly by its being locked into place by cementation. Otherwise, the dramatic density difference between hematite and quartz sand (Allen, 2001) would have concentrated the hematite.

> Hematite is most common near the base of the [Honey Creek] formation suggesting that the mineral was quickly fixed during early stages of the Franconian transgression. (Rafalowski, 1982, p. 83, brackets added).

With regard to the third question, uniformitarians envision ooids forming in quiet offshore waters, prior to transport inshore to the middle Reagan sands. The ooids are of two types, hematite on a nucleus particle or alternating bands of hematite and iron-rich illite on a particle. Most of the nuclear particles are rhyolite and clay, and Tsegay (1983) speculated that ooid formation would have been easier on a clay surface, forming in shales and then being transported to the sands. Uniformitarians note that ooid formation requires (1) a stable craton during transgression, (2) mild climate supplying iron from weathering, (3) embayed or lagoonal coastline, (4) variations in sediment supply allowing ooliths to form in low supply conditions. But there are many places in the rock record where these criteria are met and iron ooids are not present.

Iron-rich ooliths have been observed forming in shallow marine and muddy delta mouth settings as alternations of goethite and nontronite (iron smectite). If the Reagan ooids formed in this way, then the goethite has altered to hematite and the nontronite to illite. In the first transgressive shoreline sand at Bally Island, up to 15% ferruginous ooids occur. Donovan and Burcheit (2000, p. 13) are puzzled by the occurrence of the ooids.

> They are an unlikely grains [sic] to have formed in a robust shoreline setting and may well have nucleated in quieter, offshore estuarine settings prior to their reworking into shoreline sands.

Tsegay (1983, p. 57) was more straightforward.

> Unfortunately, uniformitarianism is muted where the formation of ferruginous ooliths is concerned.

One of the problems that must be overcome is the relative fragility of the ooids. They deformed easily against harder quartz grains during compaction indicating that they were relatively soft. How then, did not migrated through a relatively high-energy shallow marine setting and survive the pounding of wave action on the ancient beaches?

Glauconite is a name given to a variety of green aggregates of iron silicates, but most properly to an iron-rich monoclinic mica. It occurs in modern marine environments with a great depth range, but in minor amounts, commonly as bright green pellets, usually smaller than 0.5 mm (Blatt et al., 1980). However, "greensands," or glauconite sands occur in various Cambrian sands across the midcontinent, often spatially associated with phosphate accumulations.

> All of the sandstones above the basal shoreline sand contain some glauconite in the form of medium to fine-grained peloids that show various degrees of abrasion. (Donovan and Burcheit, 2000, p. 32).

Glauconite is found in the upper Reagan beds as peloids, rhyolite replacement, and as matrix. The occurrence of matrix glauconite in both the Reagan and Honey Creek suggest precipitation under an Eh of 0.

> However, the other two forms of glauconite, peloids and altered rhyolite fragments, are more difficult to interpret. It is probable that neither type of grain is in its original environment of formation. (Tsegay, 1983, p. 59).

Tsegay (1983) thought that the glauconite peloids, found in cross-bedded sands, and altered rhyolite were evidence of grain reworking during low sediment supply times. Phosphate occurs in two forms in upper Reagan (Tsegay, 1983) as shell fragment (all broken) and as pebbles up to 1.5 cm, usually in fringing conglomerates. Nodules also include clastic grains of quartz, rhyolite, and glauconite, replaced by collophanite. But reworking could also mean catastrophic deposition.

> Although this scenario [transgressive reworking] may well have operated during Honey Creek time, it is clear that many of the glauconite pellets were reworked as they are now found in association with cross bedded pelmatozoan sands immediately adjacent to the basal unconformity. This suggests that the Franconian transgression may have been accompanied by short term sea level oscillation. (Rafalowski, 1982, p. 82).

Short term sea level oscillation is exactly what would be found in the mixing zone of fresh and marine waters as the Flood transgressive front moved inland. The occurrence of chemically unusual sediment, concentrated in a particular zone (the upper Reagan) across a broad area speaks to rapid formation and preservation. The rapid deposition of the Flood sediments would have provided the means for preservation, and the interactions between the freshwater and marine front may have provided the rapid variations in Eh and pH that might have allowed precipitation of the glauconite forming the fragile peloids.

Flood Interpretation of the Timbered Hills Group

The currently accepted uniformitarian explanation of the Timbered Hills Group is clearly inconsistent with a history that includes the Genesis Flood as well as good science. The current interpretation focuses on processes operating over millions of years, but the observational basis for such processes must be extrapolated from poorly correlated analogs. Any viable explanation of the Timbered Hills Group must rely upon empirical data, and must recognize the interpretive role of any extrascientific frameworks. Both the biblical record and the presupposition of uniformitarianism fall into this category. Table III shows a list of empirical data discussed in the literature and deemed relevant by this investigator. Interpretations offered by uniformitarians and possible alternatives within the creationist paradigm are compared.

Data from Oklahoma indicate that the onset of the Flood included magmatic, tectonic, and sedimentary events. Figure 13 displays both uniformitarian and Flood concepts in a block diagram of the Slick Hills region. The distance from the Slick Hills area to the Ouachita front (the possible pre-Flood shoreline) is a little less than 500 km (300 mi), and the basement slope between the two

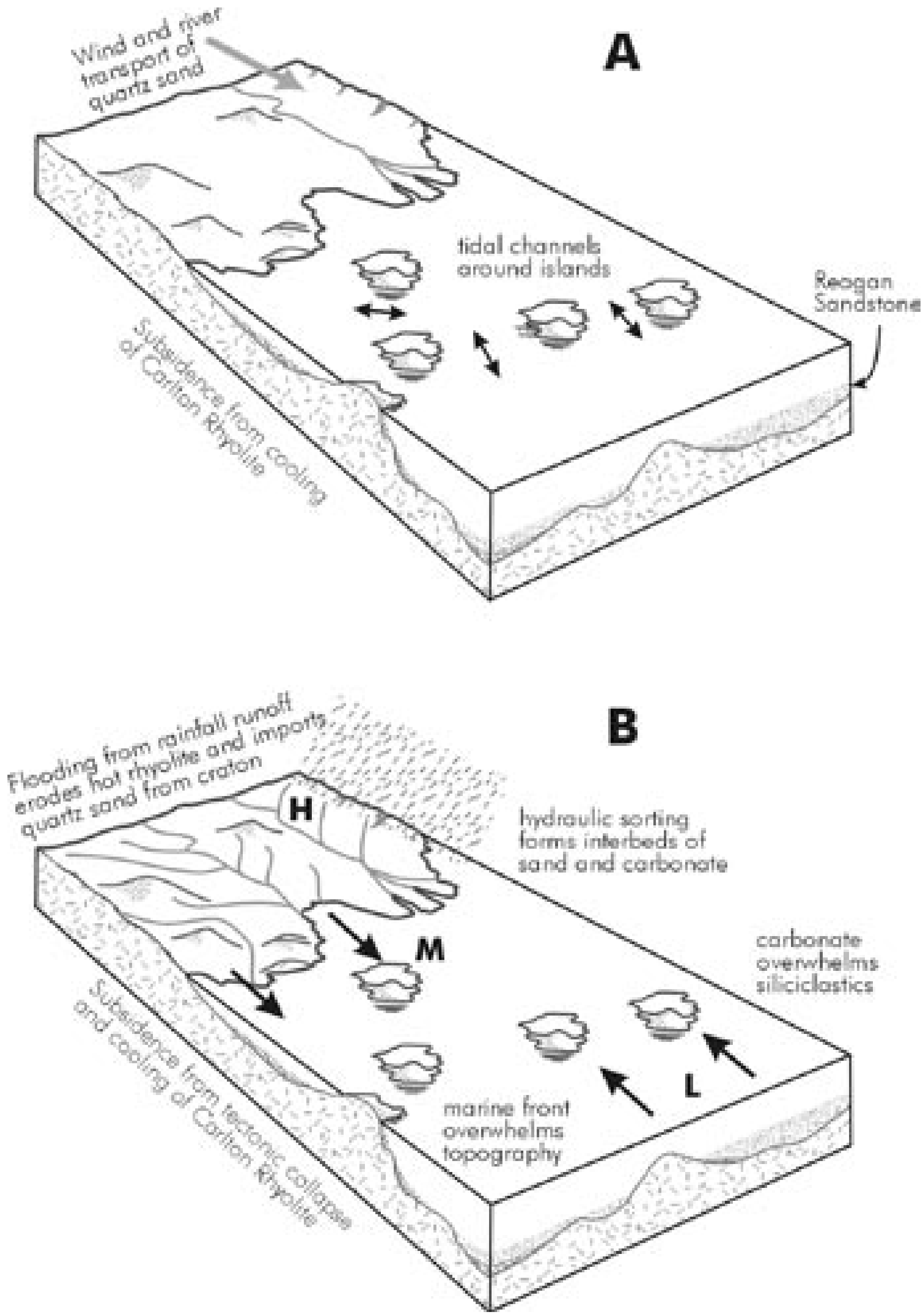

Figure 13. Block diagram of the Slick Hills region during deposition of the Timbered Hills Group modified from McElmoyl and Donovan (2000). Upper diagram (A) shows uniformitarian interpretation, based on modern-day processes operating over several million years. Lower diagram (B) shows a Flood interpretation of the same marine transgression that led to the deposition of the Reagan and Honey Creek facies. H = relatively high hydraulic energy; M = moderated hydraulic energy; and L = relatively low hydraulic energy.

points was probably insignificant. Therefore, the migration of the marine front across Oklahoma probably would not have taken many days. However, there was certainly some time before the arrival of the marine front when sedimentary processes would have been the result of rainfall and its flooding. Farther inland, this time would have been longer and its impact greater. Following the arrival of the marine front, sedimentary processes would have changed. The events that led to the Timbered Hills Group can be summarized as follows:

1. *Preparation of the basement surface.* Intense rainfall and its local flooding on the newly formed rhyolite of the SOA resulted in its rapid cooling and the creation of channels and gullies in the cooling surface. In the lower elevations, rhyolite was eroded, transported, and redeposited over short distances, but the energy of the current rapidly rose as sheet flooding covered the ground, leading to greater erosion and the breaking and rounding of individual grains.
2. *Lower Reagan alluvial facies.* Locally eroded sediment and basement debris filled channels and surface irregularities. As the marine front approached, the gradient decreased, current energy decreased, and siliciclastics began to settle out across the basement. No fossils were present in the lower Reagan beds because the freshwater runoff did not carry any marine organisms. The introduction of body fossils marked the beginning of the marine provenance. Abundant iron, contributed to the surface by expulsion of fluids associated with the volcanism, oxidized and fixed to the basal sediments as hematite (or goethite that later altered to hematite) that accumulated in the available pore space. Silica, also present in the system, precipitated as cement. Cementation was rapid due to the heat and abundance of water moving through the early pore system precipitating silica cement. The lower Reagan is supposed to represent 20,000,000 years on a marine margin. This length of time should have yielded thick, well-developed deposits. If they were eroded from the immediate area, then it should be present as thick shallow marine deposits downdip. The absence of any such sediment argues against the uniformitarian model.
3. *Marine Reagan facies.* When the marine front finally reached the SOA and the surrounding craton, transgressive sands of reworked rhyolite and quartz were deposited over the basement and the lower alluvium. Quartz began to appear in greater quantity as erosion and transport from the northern midcontinent brought increasing amounts to the migrating shoreline. The unusual geochemical environment and the abundance of iron in the water led to the precipitation of ferruginous ooids, which were mixed with the basal marine sands. Cementation was rapid, but early compaction deformed the ooids prior to cementation. The interplay of the marine transgression and the freshwater flooding resulted in a bimodal paleocurrent, with the freshwater flooding apparently having greater local energies, or having a greater source of sediments to generate migrating sand dunes out into the marine waters.

   > On the assumption that the transgression was to the northwest… flood tides were evidently less effective than ebb tides in moving sediment. In other words, the adjacent craton was a net contributor of large volumes of siliciclastics to the transgressing seaway. (Donovan, 2000b, p. 49).

4. *Upper Reagan greensand.* As the marine waters inundated the land, temperature, pH, Eh, and ionic concentrations shifted. Uniformitarians suggest that the glauconite peloids represent altered fecal pellets, but glauconite has been observed to precipitate directly from marine water under ideal chemical conditions. The concentration of glauconite peloids in a spatially widespread, but temporally restricted zone suggests their formation in a discrete, short-lived chemical environment.
5. *Introduction of carbonates.* Carbonates were introduced to the system as clastic grains, transported inland following erosion in offshore shallows. Pelmatozoan (echinoderms) fields were evidently prevalent offshore Oklahoma prior to the Flood. The pelmatozoan fields evidently included populations of trilobites and brachiopods. The lowest Honey Creek beds include abraded and broken pelmatozoans and minor shell debris, with reworked quartz, rhyolite, glauconite, and phosphate grains. A major distinction between the uniformitarian and Flood interpretations is the allochthonous origin of the carbonates in a Flood scenario as opposed to their *in situ* origin in the uniformitarian scheme. Evidence of hydraulic sorting of pelmatozoan plates and siliciclastics in their intricate interbedding suggests mixing of the two grain populations at the marine Flood front (Berthault, personal communication). Siliciclastics were transported to the zone of deposition over a wide area, as evidenced by the extent of the Honey Creek, not transported in narrow rivers whose paleochannels have not been described in the literature. Carbonate was

introduced both as grains and as dissolved ions, as evidenced by the introduction of carbonate cement. In face, the ankerite is used to mark the boundary between the Reagan and Honey Creek Formations. This raises the question as to why the stratigraphic contact is picked on a lithologic boundary that has no inherent time value. The cement also indicates unusual chemical conditions, too. If glauconite was replaced by ankerite, then the iron was mobile as Fe^{2+} and thus the environment was reducing. "The coarse crystal size and baroque morphology of much of the ankerite suggests that these diagenetic solutions were relatively hot (50°C)." (Cloyd et al., 1986, p. 20).

The irregular basement topography formed islands as the transgression progressed. The protected sides of those islands provided "dead" hydraulic areas allowing the deposition of finer grained carbonates. As the shoreline continued to migrate inland, the islands were covered by carbonates.

6. *Transition to Arbuckle Group.* The succession of interbeds of carbonate grainstone and terrestrial quartz and local debris continued well up into the Honey Creek. Near the top of the formation, however, a transition occurs. Siliciclastic contributions to the formation increase to form the "quartz spike" and then rapidly decrease, marking the removal of the inland sediment source for the area. Carbonate percentages increase rapidly; the Arbuckle Group contains very little quartz. At the same time, the percentage of carbonate mud increases significantly, marking the establishment of marine conditions over this part of the craton. The great North American carbonate shelf will be established and will persist as the Flood covers the continent. "This iron-rich siliciclastic milieu gradually gave way to a carbonate factory of unusual efficiency and duration." (Cloyd et al, 1986, p. 17).

Conclusion

A Flood explanation of the Timbered Hills Group of Oklahoma is sufficient to account for the published data. Several points stand out in favor of this model. The basement surface was eroded, swept clean of debris, and then covered before terrestrial sedimentary facies could be redeveloped, even though under the uniformitarian model, millions of years were clearly available. A hydraulic approach to deposition provides a better explanation for the sedimentary sequence than a paleoenvironmental one. The mixing of the freshwater and marine flood fronts provided a unique depositional and geochemical environment that is reflected by unusual sedimentary products: geochemically, a glauconite greensand, ferruginous ooids, and hematite cement; hydraulically, unusual interbedding of siliciclastics and carbonates through an extended section.

At the onset of the Flood, freshwater flooding from rainfall eroded the granite basement, transported sand from the cratonic interior, and rapidly cooled the lava of the Carlton Rhyolite. As ocean encroached upon the continent, possibly from as close as the Ouachita Front, hydraulic energy decreased and sand was deposited over the erosional surface. Opposing currents from the marine front and the freshwater flood gave the appearance of tidal action. Abundant iron, possibly from the ongoing volcanism, manifested itself as hematite cement, ooids, and glauconite, in that order. Marine currents transported large numbers of carbonate organisms (echinoderms) across the shallow shelf, where they were broken, hydraulically sorted and interbedded with cratonic sand. As the marine front continued inland, the clastic sources decreased until finally overwhelmed by the regional carbonate factory that marked the geochemistry of the early Flood.

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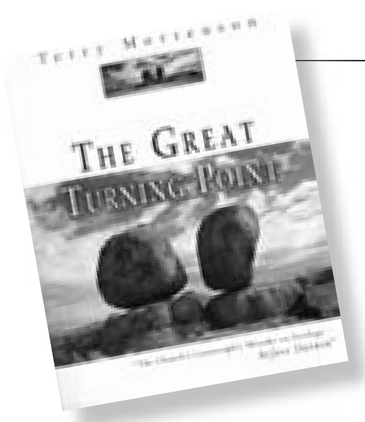

Book Review

The Great Turning Point: The Church's Catastrophic Mistake on Geology—Before Darwin by Terry Mortenson

Master Books, Green Forest, AR, 2004, 272 pages. $16.00.

Terry Mortenson describes a sad time in the Church during the early 1800s. This was a time when new ideas from the so-called enlightenment strongly invaded the Church. The Church was not only caught unprepared, but also some of the theological leaders aided the infiltration of the new ideas within the walls of the Church. Terry is not speaking of evolution, although evolution followed later as a logical consequence, but of the infiltration of the idea that the Earth is old and that the Genesis Flood was either myth, local, or tranquil. Against this trend before Darwin published, a brave group of men, most whom were knowledgeable about geology, published books and articles opposing the new uniformitarian trend, as well as the ideas of those scientists who believed the Flood was the last of a long series of catastrophes and new creations. These men are the Scriptural geologists, the subject of Terry's doctoral thesis.

I found it interesting that the Scriptural geologists had many of the same arguments that we use today. There were some inconsistencies, to be sure, but one must remember that at the time they wrote, geology was in its infancy. The most outstanding motivation of these men is that they were defending the authority of God's Word to mankind from Genesis to Revelation. It is also interesting that the Scriptural geologists received the same type of treatment from the new cultural elite as we do today. It is definitely a worldview conflict.

The reader will gain much knowledge from this book not only about our own time, but also how we arrived at the many problems unleashed on the Church and society from the invading ideas. We discover that the problems did not start with evolution, but from the precursors of evolution.

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