SEQUENCE STRATIGRAPHY AND CREATION GEOLOGY

CARL R. FROEDE JR.*

Received 3 January 1994; Revised 4 March 1994

Abstract

Sequence stratigraphy is the reconstruction and dating of sedimentary basins found locally, regionally and worldwide. Creation scientists can use many of the concepts of sequence stratigraphy within the context of the Flood model. However, the use of time intervals is uniformitarian, incorporating evolutionary concepts, and is not acceptable.

Introduction

Understanding the rise (transgression) and fall (regression) of sea level in the earth's past has proven to be an enigma to geologists. For many centuries the Biblical account of the Flood was employed to successfully explain the stratigraphic record. Perhaps because of a naturalistic bias, many scientists turned to other explanations of the stratigraphic record. One such group of men believed the earth to be very old based on their assumption of uniformitarianism. However, even these scientists have been unsuccessful in producing a model which would satisfactorily explain the stratigraphic record.

Globally, much of the stratigraphic record is interpreted as being "cyclical," with transgressive and regressive deposits reflecting the waxing and waning of sea-level (i.e., eustasy) in the geologic past. Many theories have been proposed to explain the sea-level fluctuations, i.e., Suess's "Shrinking Earth" (Hallam, 1992, p. 25); T. C. Chamberlin's "Diastrophic Control" (Dott, 1992b, p. 33): Grabau's "Pulsation Theory" (Johnson, 1992, p. 44); Udden, Weller and Wanless's "Cyclothems" (Langenheim and Nelson, 1992, pp. 60-61); and R. C. Moore's "Cyclic Sedimentation" (Buchanan and Maples, 1992, p. 76).

A new and rapidly developing concept, sequence stratigraphy, is attempting to unify not only the depositional framework but a global chronology of the associated sediments (Miall, 1990, p. 387). This paper will examine the general framework of sequence stratigraphy first within the uniformitarian context in which it is proposed (which the author does not accept) and attempt to determine what this concept might offer to creation scientists, as we seek to discern earth's past in a way that is consistent with the Flood model. Additional information regarding the specifics of sequence stratigraphy and more advanced information on its use as a framework for basin analysis, is found in Van Wagoner, J. C., H. W. Posamentier, R. M. Mitchum, P. R. Vail, J. F. Sarg, T. S. Loutit and J. Hardenbol, 1988; Posamentier, H. W., M. T. Jervey and P. R. Vail, 1988 and Posamentier and Vail, 1988.

Origin of Sequence Stratigraphy

The petroleum industry has used reflective seismic (geophysical) methods for many years in the exploration of the earth's subsurface for hydrocarbon resources. Geophysicists have discovered that many seismic reflections show geologic features which aid in finding elusive petroleum deposits. Additionally, these features have enabled the reconstruction of depositional sedimentary environments using a technique known as seismic stratigraphy. Seismic stratigraphy is based on using two-dimensional or three-dimensional seismic lines and near-by exploratory wells (as time/stratigraphic control points) in reconstructing the subsurface. Over the ensuing years advances have been made in seismic information processing, resulting in greater depth penetration and increased reflector resolution. This, coupled with additional exploratory well control, has resulted in the further refinement of seismic stratigraphy leading to the outgrowth of sequence stratigraphy see Appendix A for highlights regarding the concepts of seismic stratigraphy).

Sequence stratigraphy is formally defined as the study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or nondeposition, or their correlative conformities (Van Wagoner et al., 1988, p. 39). A key to understanding sequence stratigraphy lies in determining the position of worldwide sea-level change (i.e., eustasy) and its resulting depositional sedimentary sequences and systems tracts. Currently, two differing opinions are expressed regarding the primary cause for eustatic sea-level change.

One interpretation for eustatic sea-level change, held by Peter R. Vail and his former associates at Exxon who developed many of the concepts of sequence stratigraphy, supports the idea that most sea-level rise and fall cycles are primarily based on worldwide glacial episodes resulting in rapid eustatic change (referred to as glacio-eustatic control). This group derived the original concepts of sequence stratigraphy and sea level positions in geologic time directly from seismic stratigraphy from the North Sea, although additional input was later provided from other areas of the world (Hallam, 1988, p. 261). Central to this concept of eustatic sea-level change is the fact that tectonic forces (i.e., earth movements that cause uplift, rifting, faulting, folding and volcanism), while considered as having some effect on sea-level change, are not considered a major component. According to their interpretation the stratigraphic record reflects sedimentary conditions which require eustatic sea-level rise above any tectonic input to account for the complete sequence seen in many outcrops and well sections (Mancini and Tew, 1993; Anderson, Siringan and Thomas, 1991; Coleman and Galloway, 1991: Vail and Todd, 1984). However, it is cautioned that each site will require its own interpretation, in terms of glacial versus tectonic control (Posamentier, et al., 1988, p. 125).

These scientists have been criticized for publishing sea-level curves (Figure 1) with proprietary Exxon

*Carl Froede, Jr., B.S., P.G., 2895 Emerson Lake Drive, Snellville, GA 30278-6644.

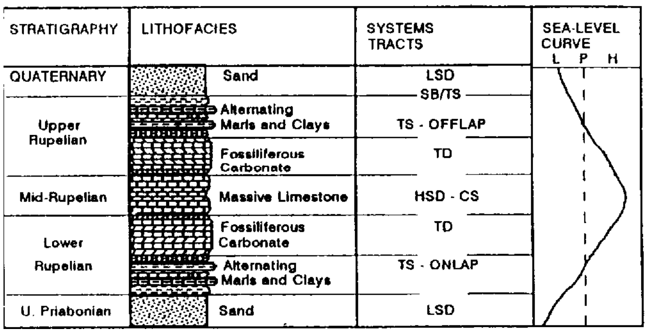

Figure 1. Hypothetical stratigraphic interpretation showing how eustatic change is recorded in the sedimentary record. Abbreviations used: LSD-Low Stand Deposit, SB/TS-Sequence Boundary/Transgressive Sequence, TS-OFFLAP-Transgressive Sequence exhibiting a "regressive" sedimentary sequence, TD-Transgressive Deposits, HSD-CS-Highstand Condensed Section Deposits, TS-ONLAP-Transgressive Sequence exhibiting a "transgressive" sedimentary sequence, L-Lower sea-level than present, P-Present sea-level, H-Higher sea-level than present. See text for additional information.

information which cannot be verified (Miall, 1986, p. 131; Hubbard, 1988, p. 49) or using sea-level curves without consideration of obvious inconsistencies (Miall, 1991, p. 504; Dockery, 1991, pp. 141-150). Additionally, it appears that some sea level curve charts provide too much flexibility to the user, allowing the user to "fit" the data in question to a Vail sea-level curve event (Miall, 1992, pp. 787-790).

The other interpretation regarding eustatic sea-level change is summarized with the following statement:

> Though many long- and short-term cyclic events of sea-level change can be documented, and many can be correlated worldwide, it is at present virtually impossible to correctly apportion the changes to the appropriate balance of tectonic, eustatic, and other causes (Miall, 1990, p. 448).

This interpretation is based on the idea of tecto-eustatic control or that tectonism plays a larger role in sequence stratigraphy than is currently accepted (Miall, 1986, pp. 136-137; Sloss and Speed, 1974, p. 118; Klein, 1982, p. 17). Computer simulation models reconstructing the stratigraphic record from actual areas have been used to demonstrate sea-level change "cycles" (i.e., Third-Order Cycles) as a function of tectonics alone (Cloetingh and Kooi, 1990, p. 127; Plint, A. G., N. Eyles, C. H. Eyles and R. G. Walker, 1992, pp. 19-20). While multiple glacial episodes are not discounted, they are not viewed as the primary mechanism in all sea-level changes. Additionally, the multiple glaciations necessary to account for the short-term change of sea-level do not become readily apparent when examining the rock record (Miall, 1986, p. 137; Van Wagoner, J. C., R. M. Mitchum, Jr., K. M. Campion, K. M. and V. D. Rahamnian, 1990, p. 50).

Eustatic Mechanisms

The primary mechanism recognized by both groups to explain the onset of ice ages and other climatic changes, within the framework of sequence stratigraphy, is the Croll-Milankovitch (Dott, 1992a, p. 2) theory of orbital forcing. This mechanism is based on solar radiation variations caused by eccentricities in the Earth's orbit (wobble and tilt) which do not directly result in glacial events but coupled with various other parameters can result in a glaciation (Dott, 1992a, p. 2; Miall, 1990, pp. 487-490; Schwarzacher, 1991, pp. 855-863). While there is general acceptance of the Milankovitch theory, many questions remain as to its actual role in climactic changes (Klein, 1990, pp. 455-457; Dott, 1992a, p. 14; Miall, 1990 p, 490). Additionally, Oard (1984a, 1984b, 1985) provides an excellent evaluation advocating a rejection of the Milankovitch theory from a creationist position.

The mechanism used to explain tectonic processes is the plate tectonic model, as originally proposed by Wegener (1929, p. iii) and modified to date. Both orbital forcing and plate tectonics play roles in eustasy and the resulting sediment sequences which are deposited.

Concepts of Sequence Stratigraphy

Sequence stratigraphic interpretation uses facies analysis, through the application of Walther's Law, to reconstruct eustatic sea-level positions. The interaction of eustasy with local tectonics and sediment supply determines the stratigraphic pattern of development (Posamentier et al., 1988, p. 124). Sequence stratigraphy has also been called a special type of event stratigraphy (Miall, 1990, p. 387) and according to P. R. Vail, F. Audemard, S. A. Bowman, P. N. Eisner and C. Perez-Cruz (1991, pp. 617-659), can be used to determine the interplay of tectonics, eustasy and sedimentology on the depositional sequence formed.

The "sequence" is the largest definable unit within the framework of sequence stratigraphy and it is composed of various transgressive and regressive assemblages (Figure 1). It is defined by Van Wagoner et al. (1988, p. 39) as being bounded by unconformities and their correlative conformities. Two types of sequences are recognized in the rock record (Van Wagoner et al., 1988, p. 41). They are the "Type 1" and "Type 2" sequence. The Type 1 sequence is the more complex of the two in that a greater variety of sedimentary facies can develop. According to Swift, D. J. P., P. M. Hudelson, R. L. Brenner and P. Thompson (1987, p. 448), Type 1 depositional sequences are built on thermally subsiding continental margins whose tectonic hinge point occurs landward of the region in which the sequences form. Space for sedimentary deposits (accommodation space) is created by eustatic sea-level rise, as modified by differential thermal subsidence of the continental margin. The upper and lower sequence boundaries are cut by a sea-level fall which exposes the sequence boundary to subaerial erosion.

The Type 1 sequence is composed of five different sea-level positions, which are reflected through their associated stratigraphic assemblage, referred to as 'Systems Tracts." These five systems tracts are: (1) Highstand systems tract [Figure 2], (2) Lowstand systems tract-Lowstand fan [Figure 3], (2) Lowstand systems tract-Lowstand wedge [Figure 3], (3) Transgressive systems tract [Figure 4] and (5) Highstand systems tract II [Figure 2] (Posamentier and Vail, 1988, pp. 126-129). The figures provided show the sea-level positions in a terrigenous deposition setting. A discussion with figures showing the carbonate deposition setting can be found in James and Kendall, 1992. All of these "Tracts" reflect eustatic change as sea-level moves from a maximum high through the minimum low and returns to the maximum high point again (Posamentier and Vail, 1988, pp. 126-129).

Eustatic lowstands may result, in some cases, in the exposure of the continental shelf or even the continental rise to subaerial conditions. Exposure of the continental shelf to erosion during a sea-level lowstand results in surface runoff coalescing into stream drainage channels which entrench themselves (i.e., incised drainage valleys) into the shelf surface. Usually an erosional unconformity marks the boundary between the lowstand and subsequent sea-level rise (Van Wagoner, J. C., R. M. Mitchum, Jr., Campion, K. M. and V. D. Rahamnian, 1990, p. 30). Deposits from the eroded uplands as well as from the shelf surface serve to fill the incised drainage valleys (unconformity surface) before transgressive material is deposited. These infill deposits (i.e., incised-valley-fill deposits) exhibit a wide variety of rock and/or sediment types due to the distance of the source area to the sea (Van Wagoner et al., 1990, p. 31; Blum, 1991, 71-83). An excellent summary for the development of a Type 1 sequence is provided in Swift et al., (1987, p. 448):

> Deposition of the sequence begins as sea-level rises. At first, the rise rate is too slow to accommodate the sediment input, and shelf deposits prograde seaward [Transgressive "off lap" systems tract]. If sea-level drops over the shelf edge during the fall, shelf-edge deltas form during this early regressive phase [Type 1 sea-level Lowstand]. However, as the sea-level enters the main phase of the rise and the rise rate increases, the sediment input rate (assumed to be constant) is no longer sufficient to fill the space being created by subsidence and the regression turns to transgression. The shoreface is driven back over back-barrier lagoonal and estuarine deposits, creating a ravinement surface. Transgressive marine shales onlap the ravinement surface, but as the sea-level rise rate attains its maximum value, the sediment accumulation rate drops [sea-level Highstand]. Condensed section, enriched in authigenic components, culminates in a burrowed omission surface. As sea-level approaches highstand, and the rise rate slows, sediment input is once more able to cause the shoreline to prograde, and regressive shelf sediments downlap over the condensed horizon. *[Brackets added]*

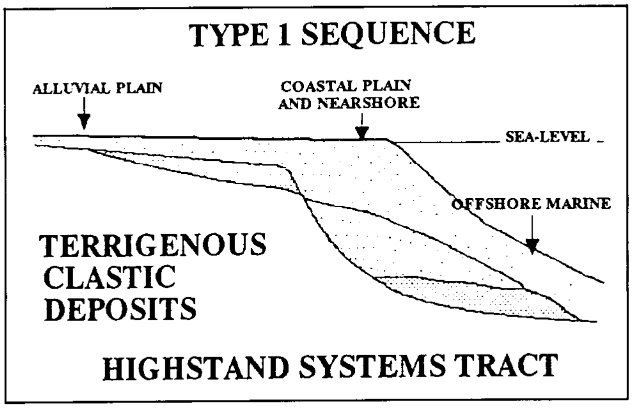

Figure 2. Cross-section showing generalized profile of a clastic Highstand Systems Tract, Type 1 Sequence. The Type 1 Sequence results in the exposure of the continental shelf to subaerial erosion. Redrawn and modified from James and Kendall, 1992.

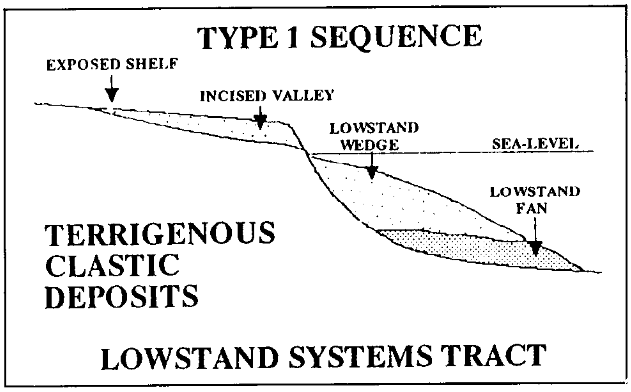

Figure 3. Cross-section showing generalized profile of a clastic Lowstand Systems Tract, Type 1 Sequence. Redrawn and modified from James and Kendall, 1992.

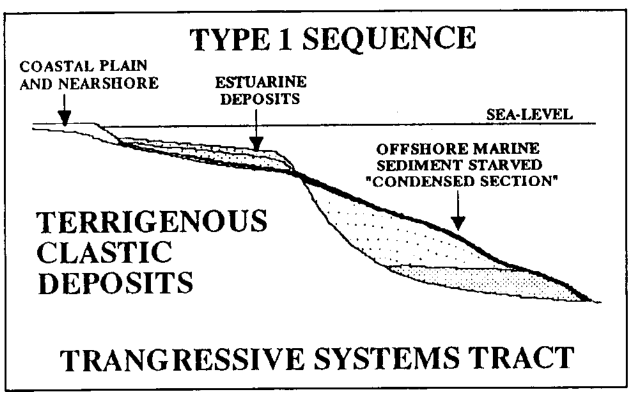

Figure 4. Cross-section showing generalized profile of a clastic Transgressive Systems Tract, Type 1 Sequenee. This section shows the sequence formed during a rise in sea-level. Note incised drainage valley is filled with shallow/near shore deposits, usually associated with tectonic or storm events. Redrawn and modified from James and Kendall, 1992.

The Type 2 sequence is characterized by subsidence during sedimentary deposition providing additional space for sedimentation and resulting in no exposure of the continental shelf surface to subaerial conditions (Figure 5). This particular sedimentary depositional package is called a "Shelf Margin Systems Tract" (Posamentier and Vail, 1988, pp. 144-145). This systems tract reflects neither maximum highstands nor minimum lowstands, rather the sedimentary basin "accommodates" the sedimentary influx resulting in a kind of depositional equilibrium on the continental shelf.

Both Type 1 and Type 2 sequences can be subdivided into successively smaller sedimentary units (i.e., systems tracts, parasequence sets, parasequences, bedsets, beds, laminasets and lamina) which reflect the depositional environment in which they were formed (Van Wagoner et al., 1990, pp. 6-7).

Unconformities and disconformities serve as both major and minor boundary surfaces. They are used to identify sequences (Type 1 or unconformity), systems tracts, etc., and reflect, in some cases, sea level position during the deposition or nondeposition (i.e., hiatus or condensed section) of sediments. Many of these uncon-

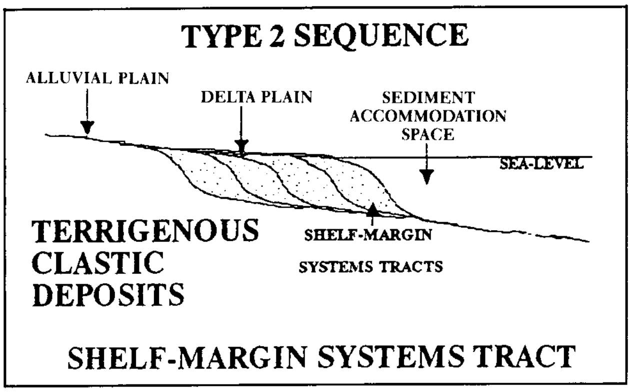

Figure 5. Cross-section showing generalized profile of a clastic Shelf Margins Systems Tract, Type 2 Sequence. Sediment accommodation space is created without a change in sea-level, shelf exposure to subaerial erosion does not occur. This sequence can form anywhere that sediment is deposited, including between Type 1 Sequences. Redrawn and modified from James and Kendall, 1992.

Table I. Five types of stratigraphic cycles, each with a specific cause and range of duration (modified from Miall, 1990, p. 447; Vail et al., 1977, pp. 83-98; Haq et al., 1988, p. 75.

Type	Other terms	Duration* m.y.	Probable cause
First order	Megasequence	200-400	Major eustatic cycles caused by formation and break up of supercontinents
Second order	Supercycle; Sequence; Supersequence	10-100	Eustatic cycles induced by volume changes in global midoceanic spreading ridge system
Third order	Mesothem; Megacyclothem;	1-10	Possibly produced by Sequence ridge changes and contenental ice growth and decay
Fourth order	Cyclothem; Major cycle; Sequence; Parasequence	0.2-0.5	Milankovitch glacioeustatic cycles, orbital forcing
Fifth order	Minor cycle; Parasequence	0.01-0.2	Milankotitch glacioeustatic cycles, orbital forcing

*Uniformitarian estimates (not accepted by author).

formity boundaries serve as points of stasis and result in the development of faunal communities. The preservation of the community was usually the result of a catastrophic event (Pemberton, S. G., J. A. MacEachern and R. W. Frey, 1992, p. 58).

Uniformitarian stratigraphers believe that sequence stratigraphy can age date sediments not only locally, but globally. The conventional dating of sedimentary deposits is achieved via the use of biostratigraphy, lithostratigraphy, magnetostratigraphy, radioisotope dating and amino acid racemization. All of these are based on the standard evolutionary geologic timescale. Biostratigraphy remains the primary tool in the age determination of marine sediments. Additionally, sediments can be tied to eustatic cycles and allegedly provide sediment age dates to within 10,000 years (Miall 1990, p. 447). Correlations between basins are based on matching age dates using the above referenced dating methods. According to Vail (1992, p. 90):

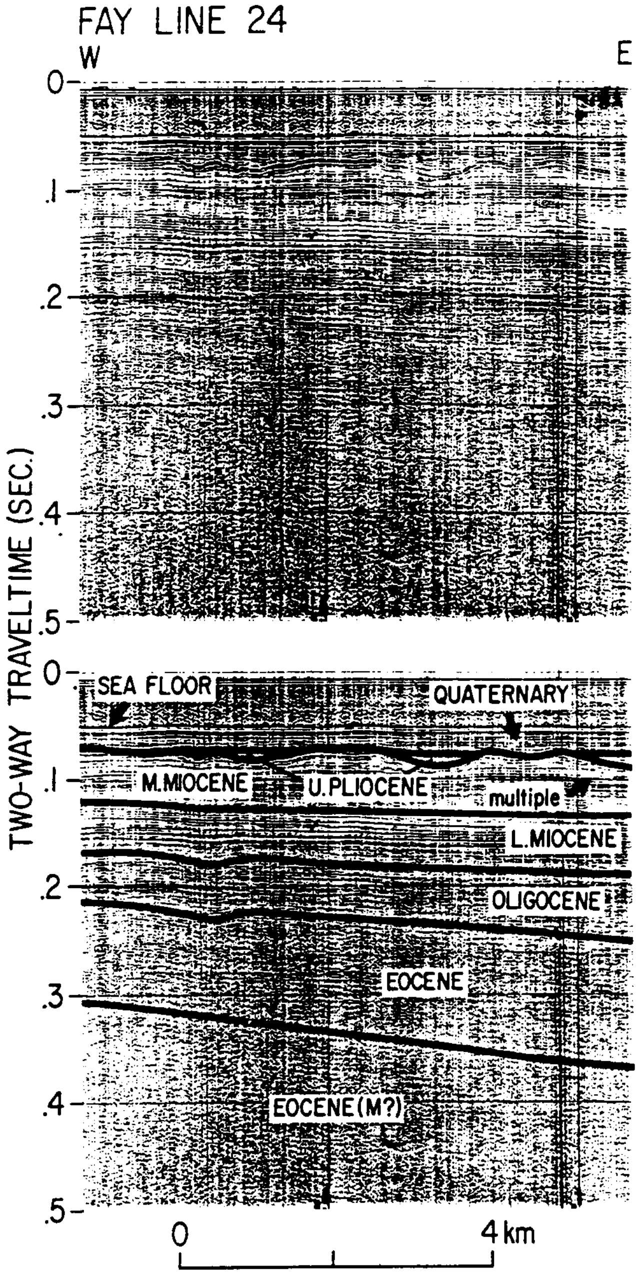

Figure 6. Two seismic lines are shown. A) Top figure shows only the processed information with vertical scale in time. There is no way of knowing what lithologic units are shown and the depth they exist below the ground surface. B) Bottom figure shows the stratigraphy which is based on lithologic and biostratigraphic information gained from nearby wells. This specific seismic section is from the continental shelf off Georgia. From Popenoe, 1992.

Sequence stratigraphy has evolved from the early concepts of Sloss, Krumbein, and Dapples (1949) and Sloss (1963) through the addition in the 1960s of seismic and well-log data (Payton, 1977) to conventional outcrop and biostratigraphic data (Posamentier et al., 1988). Additionally this concept has served to unifying sedimentary basinal analysis and age dating much like “Plate-Tectonics” did for geology and geophysics.

Eustatic cycles, seen in the stratigraphic record, have been assigned different orders of magnitude, due to the different causes which resulted in sea-level change. Currently there are five types of stratigraphic cycles, each with a specific cause and range of duration (See Table I). Additional information regarding stratigraphic cycles can be found in Van Wagoner et al., 1990 and Miall, 1990.

Sequence stratigraphy has renewed interest in sedimentary deposition and facies analysis. This concept is being used in the reconstruction of both clastic (Van Wagoner et al., 1990; Van Wagoner et al., 1991; Walker, 1992) and carbonate (Schlager, 1992; James and Kendall, 1992) depositional environments. Additionally, sequence stratigraphy is not just for subsurface analysis. It is being used to reconstruct sedimentary basins which are exposed on the earth's surface.

While sequence stratigraphy has renewed interest in stratigraphic correlation of sedimentary environments and the associated fauna, it has not gained wholesale acceptance. Many geoscientists have sought to approach the stratigraphic record using unconformity/disconformity bounding surfaces as stratigraphic dividing units (Walker, 1990, p. 785; Walker, 1992, pp. 1-14). Recognition of the importance of unconformities in the stratigraphic record has led to a proposal for a new class of stratigraphic unit, termed the allostratigraphic unit (NACSN, 1983, pp. 867-868) which is identified as a mappable stratiform body of sedimentary rock that is defined on the basis of its bounding discontinuities 1983, p. 867). These stratigraphic units are also considered a part of event stratigraphy (Miall, 1990, 86). While there are similarities between allostratigraphy and sequence stratigraphy there are considerable differences. One major difference is that sequence boundaries can be identified beyond the extent of their bounding unconformities by correlating their correlative conformities. Allostratigraphic units are recognized only where their bounding unconformities or disconformities can be identified (Baum and Vail, 1988, p. 309). There are many ways to interpret the stratigraphic record and as easy as it might seem to follow a certain approach, the stratigraphic record remains in many cases ambiguous and subject to more than one interpretation. Additionally it has been noted that there is a certain amount of "recycling" of stratigraphic concepts which present themselves for a while, are later thrown out for something else and still later resurface under a new name slightly modified (Walker, 1990, p. 777).

Creationist Approach to the Sequence Stratigraphic Framework

It is the author's opinion that many of the concepts within the framework of sequence stratigraphy are relevant and easily adapted for use by creationists. However, there are several aspects of this concept which cannot be accepted, specifically the evolutionary aspects, concepts of uniformitarianism and the ancient age of the earth. In an effort to better examine the concepts of sequence stratigraphy, a quick review of the Flood model is required, then the concepts of creationist sequence stratigraphy will be discussed following the review.

Antediluvian World

The Antediluvian world existed from the "Creation" to the "Flood." This time period is not exact but could be estimated (using inexact biblical "generations") as being approximately 1,200 to 1,656 years in duration (Whitcomb and Morris, 1961, p. 26). The antediluvian earth had mountains (Genesis 7:20), rivers (Genesis 2:10) and seas (Genesis 1:10) and so must have experienced geological activities similar to present processes with several exceptions, most notably that it did not rain (Genesis 2:5) [modified from Whitcomb and Morris, 1961, p. 215]. During this timeframe there was probably minimal geologic deposition occurring. The author believes that sediments were deposited as stratified layers (Genesis 1:6), but without any "dead" life forms (fossils) in them prior to the Fall. Everything in the antediluvian world was created perfectly suited to its environment, be it terrestrial or marine and there was no death prior to the Fall. After the Fall, sediments could possibly have been deposited containing flora and fauna, however, the rate and amount of sedimentation would not have been conducive to mass burial of lifeforms.

The Flood

The author believes that the beginning of the Flood resulted in the first occurrence of rain and the breaking up of the earth's surface resulting in the release of subterranean waters (connate and juvenile) and volcanic materials (i.e., gases and ash). This created an erosional environment on the continents and depositional environments in lakes, seas and along the continental shelves and slopes. The author supports the "Ecological Environment" burial model, in certain instances, as proposed by Whitcomb and Morris, 1961, p. 276; Coffin, 1983, p. 69-81; Gish, 1985, p. 50. However, Burdick (1976, p. 37) has pointed out that the paleocommunity might not have really existed, but be the result of selective transport of flora and fauna. Caution must be used by the creation scientist when attempting any paleoenvironmental reconstruction.

Genesis 7:20 states that the Flood water covered the earth to a depth of at least 15 cubits (approximately 22 ft) within the first 40 days. Following the end of the rain the waters covered the face of the earth for another 110 days and then began to recede. The earth, during this time, did not have an underwater surface of equal elevation and would have provided variation in depositional conditions. High areas would have been eroded with those sediments being deposited either locally or carried away by oceanic currents. Clark, M. E. and H. D. Voss (1990, pp. 53-63) have suggested that amplified tidal induced waves could possibly have circled the globe during the Flood event. This activity would have contributed significantly to the erosion and deposition of sediments and could account for the thick sedimentary sequences seen globally. Additionally, the author suggests that other global oceanic currents would be generated by a number of forces during this time frame, however, mainly by gravitational force and winds. For instance, as the Flood waters receded, winds blew across the face of the earth (Genesis 9:1). These winds would generate currents which could result in the erosion, resuspension and subsequent deposition of those sediments. Evidence for this occurrence can be found in the trace fossil record, with the development of several ichnofacies in substrate at various depths and their subsequent burial due to catastrophic sedimentation.

The Post-Flood World

According to Whitcomb and Morris (1961, p. 8), Noah and his family departed from the ark 371 days after entering it. Major climatic changes had occurred and tectonic forces were slowing down from their earlier activities associated with the breakup of the fountains of the deep. Sea-level across the globe was in the process of regressing. Additionally, we do not know the position of sea-level when Noah and his family departed from the ark. Possibly it was higher than present.

During the latter stages of the Flood, tectonic forces, still incompletely understood, created basins into which waters flowed, thereby exposing earth's surface. Orogenic (mountain building) events, recognized throughout the geologic record, would have occurred throughout the Flood event and slowed following the recession of Flood waters. Most of the mountain ranges covering the earth's surface today formed in the Cenozoic era (this author believes that this era is Late-Flood / Post-Flood / Early Ice Age time frame). Additionally, massive volcanic deposits cover the earth either as altered volcanic ash or as lava flows and "date" from this era. Cyclic depositional features (i.e., coal) could have developed due to the presence of shallow areas whereby woody materials might have become "grounded" on the uplifted sediments and buried with further sedimentary and volcanic activity. Woodmorappe (1978) has proposed a possible model for the formation of cyclic sedimentation using the Flood model.

Volcanic materials and possibly meteorite materials (i.e., Iridium, etc.) could have been deposited during this time of Flood water withdrawal. Some concentrating of these deposits might have occurred if they were eroded and redeposited in a limited area.

Drainage of water from the Earth's surface had created river channels larger than present. The increase in precipitation occurring immediately following the Flood event (Oard, 1990, p. 60) resulted in a fresh water flush of the continents and provided the source waters for the further development of streams and rivers as they were established on the continents. Sea-level would continue to drop as a result of continental plate spreading and the sinking of oceanic basalt during cooling, accommodating greater volumes of water (Schopf, 1980, p. 48).

The Return of Plant Life

As the Flood waters receded and precipitation associated with climatic disequilibrium occurred, the continents would reestablish ground cover and forests would start to grow once again. According to Odum (1971, p. 261) terrestrial ground cover could go from nothing to grasses in 0 to 2 years; from grasses to shrubs in 3 years or less; from shrubs to pine forests in 25 years and from pine forests to Oak-Hickory forest climax in approximately 150 years.

The Ice Age

This author supports the single "wet" ice age as outlined by Michael Oard (1990) and believes that the combination of tectonic forces coupled with climatic instability contributed to glacial dis-equilibrium resulting in the rapid rise and fall of sea level during the ice age and subsequently thereafter until the climate reached its present state. This ice age would directly result in the very rapid change in eustatic sea-level due to the rapid buildup of continental glaciers: lowering sea-level and the melting of the glaciers with the resulting sea-level rise. This in turn would result in a cyclical transgression / regression pattern of sedimentation seen on the continents and continental margins. Additionally, this eustatic change coupled with tectonic uplift could have resulted in the exposure of "land bridges." These land bridges would serve migrating people as they moved from continent to continent, following the dispersal at the Tower of Babel.

Some of the most obvious physical signs of heavier than present rain and snow conditions which occurred during the ice age are that many of the streams and rivers (meandering and braided) are choked with sediments they were unable to wash to the seas and oceans following the melting of the continental glaciers. River valleys and their associated channels which drained the continents during this ice age time frame were several times larger in width and depth than at present. Today these underfit rivers and streams look out of place in their wide valleys (e.g. Mississippi River, MS; Columbia River, WA; Pascagoula River, MS, etc.).

Another important circumstance to consider in this time frame is the amount of sediment washed from the (unforested) continents and deposited in deltas (both on and off the continental shelf. Some of the world's largest deltas (i.e., Nile, Mississippi, Amazon, etc.) are composed of "Cenozoic" era sediments. Many of these sediments could have been deposited during the last stages of the Flood event and the early stages of the ice age time frame.

Present Day

Today's sea level is estimated to reflect 4,000 to 7,000 years of more nearly stable conditions Dolan and Lins, 1986, p. 13; Curray, 1965, p. 733), which is consistent with the creationist's model (especially if the earth is no older than 10,000 years). While sea-level has fluctuated somewhat in the recent past, no major sea-level changes have occurred as a result of a new ice age event or the melting of our present polar ice caps or glaciers. The sea-level changes which have occurred are the result of tectonic activity associated with volcanism (i.e., areas around the Mediterranean Sea), isostatic rebound of continental ice sheets (e.g., Scandinavia) or the slow rise in sea-level as a result of changing climatic conditions associated with the melting of present glaciers (e.g., U.S. East Coast barrier islands).

Creationist Cause for Sea-level Change in Sequence Stratigraphy

The broad framework of sea-level rise and fall over the geologic past is clearly acceptable within the Flood Model. We know from Scripture that the Flood event resulted in water covering the complete surface of the earth. Sea-level would drop with the receding of the Flood waters into ocean basins. The ensuing wet ice age would result in rapid buildups of ice on the exposed and unvegetated continental landmasses, including the

Antarctic. The ice age would contribute to additional erosion of sediments as large amounts of water would be evaporated from the seas and oceans and be precipitated both as snow and rain. According to Donovan et al. (1988, p. 301), as sea-level drops and sediment deposition occurs further out on the continental shelf/slope, progressive starvation of terrigenous sediments occurs and other sedimentary materials such as volcaniclastics, cosmogenic debris and authigenic minerals can accumulate in significant quantities. Water runoff from the continental landmass would coalesce into river channels entrenching themselves (incised drainage valleys) into the continental shelves. The increase in precipitation would result in the erosion of exposed land surfaces. Previously deposited sediments would be "washed" away as sea-level fell, exposing them to erosion; the Cretaceous/Tertiary boundary is known to be a "regressive" boundary almost world-wide and the sediments associated with this boundary are not present and are believed to have been eroded (Donovan et al., 1988, p. 305; Loutit et al., 1988, p. 200). Rapid eustatic sea-level change caused by the formation, storage and release of water associated with the continental glaciers would contribute to eustatic changes and rapidly affect the sedimentary depositional environmental framework until the various eustatic mechanisms (i.e., climate and tectonics) would stabilize to present levels.

The determination of real versus apparent eustatic change in sea-level can be further complicated by an increase in sediment input (caused by tectonic events and/or by an increase in precipitation which could lead to a false assumption of sea-level fall strictly based on sedimentary buildup (Jervey, 1988, p. 69; Miall, 1990, p. 392). The Flood model would allow for this due to the increased precipitation and erosion associated with the end of the Flood and beginning of the Ice Age time frame.

The Creationist Perspective Regarding Tectonic Forces

The author believes that tectonic forces, initially starting with the onset of the Flood event, would have remained active as the Flood waters receded. During and immediately following the Flood the continents experienced both vertical and horizontal movement due to seafloor spreading, plate subduction and continental collisions. With the cooling and sinking of the freshly formed basalt seafloor (Schopf, 1980, p. 48) greater space would become available draining water from the continents. These same tectonic events would serve as geological forces in the generation of Tsunamis (possibly resulting in the resuspension of newly deposited sediments) and subaerial and subsurface volcanic eruptions (generating new sediments above those previously deposited during the Flood), but would lesson following the end of the Flood. The newly formed mountain ranges would provide the land surface necessary for the Ark's eventual landing. These forces coupled with the ensuing wet ice age, would have created conditions of complicated eustatic change. The Ice Age time frame would have created fluctuating sea-levels which, coupled with still active tectonic forces, could have resulted in the exposure of the then existing continental shelves to subaerial erosion. Tectonic movement coupled with several periods of glacial buildup and retreat could have resulted in the formation of correlatable cyclical deposits in sedimentary basins around the globe.

As previously described, the resulting eustatic change would have been a function of both tectonics and glaciation. This would prove complicated in interpretation and while local basinal correlation might be possible, regional or global correlation would exhibit the same problems that uniformitarianists are facing (i.e., inexact dating and no direct match).

Creationist Dating Methods for Sequence Stratigraphy

The geologic dating methods commonly used by evolutionary sequence stratigraphers include: radiometric, biostratigraphic, lithostratigraphic, sea-floor spread rates and the associated reversals and polar wandering, oxygen isotopes and amino acid racemization. These dating methods will not be examined or discussed because they are based on the uniformitarian concepts of evolution over vast eons of time. See Haq et al. (1988) for additional information.

Under the creationist model many of the sequences both locally and globally might be correlatable due to the limited time of the Flood event and the ensuing ice age. Hence, the creationist time frame for sequence development would involve hundreds, possibly thousands of years, not the millions proposed by uniformitarianists. So while the evolutionary sequence stratigraphers discuss ice ages in the Cambrian, Permian, Quaternary, etc., we can discuss one ice age which impacted various parts of the planet at different stratal "ecological" positions. Excellent creationist perspectives on the usefulness and validity of uniformitarian dating techniques are presented in Oard, 1984a, 1984b, 1985; Slusher, 1981; Von Fange, 1990; Brown, 1997; Humphreys, 1987; Overn and Arndts, 1987; Overn, 1986; Wise, 1986; Woodmorappe, 1979; Whitelaw, 1993, and Helmick, 1976.

Conclusion

With the basic concepts of sequence stratigraphy in mind, creation scientists can approach the stratigraphic record and seek to understand its significance in relationship to the Biblical account of its occurrence. Clearly this concept, probably more than any other developed in the area of uniformitarian stratigraphy, holds great promise for creationists in understanding how the Flood event and ensuing ice age have shaped earth's geologic past. Sequence stratigraphy is the reconstruction of depositional sedimentary environments, but more than that it can aid the creation scientist in determining when deposits were formed (time frame) and potentially how they were formed. We now have another tool with which we can define sea-level changes (within the young earth Flood model) and confidently defend the creationist position that sea-level has changed globally in earth's past. As we refine the creationist model using concepts like sequence stratigraphy, we can provide to people who chose to follow the evolutionary framework a better model to explain the stratigraphic record. The author hopes to follow this generalized work with additional articles which will present specific sites and their sequence stratigraphic interpretation within the young earth Flood model.

Acknowledgements

The author thanks Jack H. Cowart and Dr. E. L. Williams for the editing they did on this document, and to my wife, Susan who gave me the time to complete this work. Additional thanks are expressed to Dr. E. F. Chaffin for suggesting creationist reference material and the anonymous reviewers who helped make this a better paper.

Glossary

Connate water—water trapped in sediments at the time of deposition.

Conformity—a bedding surface separating younger from older strata, along which there is no evidence of erosion (either subaerial or submarine) or non-deposition, and along which no significant hiatus is indicated.

Disconformity—Unconformity between parallel strata. No change in dip occurs between the strata.

Eustasy—Of or pertaining to worldwide sea-level.

Event stratigraphy—recognition, study and correlation of the effects of significant physical events (storms, floods, turbidity currents, volcanic eruptions or any other event which is not a regular event in that environment, i.e., catastrophic), or biological events (e.g. extinctions) for continents or even the whole globe.

Juvenile water—Water resulting from its release during volcanic emanations.

Offlap—The progressive withdrawal of the sea from the land reflected in the associated sedimentary deposits.

Onlap—The progressive submergence of land by an advancing sea reflected in the associated sedimentary deposits.

Orogeny—The process of forming mountains.

Unconformity—A surface of erosion that separates younger strata from older material (i.e., rocks, strata, sediments, etc.).

Uniformitarianism—The concept that the present is a key to the past and that past geologic events are the same as occur today.

Walther's law of facies—a vertical sequence of facies will be the product of a series of depositional environments which lay laterally adjacent to each other.

APPENDIX A

Seismic geophysical methods have increased in usage due to computer technology. The computer "processes" the seismic line information and allows the user to define and refine the final output information. A seismic line is generated by bouncing seismic waves off of a subsurface lithologic boundary by way of an energy source (e.g., originally dynamite was placed into a shallow drill hole and detonated or a steel plate was placed on the ground and hit very hard with a heavy sledge hammer). Today there are a number of sophisticated energy sources available. The energy source is captured by geophones (magnet recording devices pushed into the ground in a certain pattern and connected by way of an electric cable to a recording device) which records the reflected signals as the energy waves move into the earth and bounce upward. A nearby well is used to correlate the reflector events with lithology. However, as seismic lines can represent several miles in length, additional well control points are necessary to ensure that lithologic changes are accurately delineated.

One of the biggest advances in seismic processing has come from increased resolution capabilities. Originally the reflectors (geologic units) had to have sharp contrast boundaries and significant thickness to differentiate them from background noise. This meant that the reflector events could be no less than 150 feet thick or they could not be "seen" apart from background. Within the last 15 years seismic line processing and better equipment have resulted in reflector event resolution down to 30 feet in thickness (Shefiff, 1980, p. 165). This allows a finer amount of detail in interpreting the subsurface. Seismic lines, coupled with well log control, have been used to reconstruct sedimentary depositional basins (e.g., Gulf of Mexico, North Sea, etc.). Transgressive and regressive sedimentation has been recognized on a worldwide scale and its reconstruction using seismic information has resulted in the outgrowth of the concepts of sequence stratigraphy. Figure 6 shows an actual interpretation of a seismic line shot midway across the continental shelf located off the Georgia coast (Popenoe, 1992). This seismic line provides a good example of how seismic data are interpreted using well control. The reader can see that using this method can greatly aid in understanding subsurface lithology on a large scale. Additionally, based on the lithology and macro / microfossils found from the well control points, the sea-level position could be approximated. Note however, that sea-level position does not necessarily reflect eustatic change due to the role of tectonism, which cannot be determined (i.e., was the basin subsiding or stable in relation to sea-level rise?)

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A fault surface in the Tule Mountain Trachyandesite Member of the Chisos Formation. The fault moved laterally from right to left in the photograph. This exposure is located 3 miles west of Lajitas, Texas on FM 170. The geologist showing us this site claimed that it is the best exposure of a fault surface in the world. The Tule Mountain lava consists of approximately 60% SiO_2. Photograph by Glen Wolfrom, caption by Emmett Williams.