Using Suites of Criteria to Recognize Pre-Flood, Flood, and Post-Flood Strata in the Rock Record with Application to Wyoming (USA)

John H. Whitmore, Ph. D., Cedarville University, 251 N. Main Street, Cedarville, OH, 45314
Paul Garner, BSc (Hons), Biblical Creation Ministries, Soham, Cambridgeshire, UK

Abstract

We propose a method using suites of criteria to help establish pre-Flood, Flood and post-Flood strata. Our method is independent of chronostratigraphic indicators (that is, radioisotope dates and zone fossils); instead it relies on other criteria. Application of this model is made using the lithostratigraphic section from Wyoming and vicinity (USA) as an illustration of how the criteria model should be used. Not only can this model be used to help more confidently determine Flood boundaries, but it might be used as a test to see whether we can rely on chronostratigraphic or biostratigraphic units to determine Flood boundaries elsewhere. Properly understanding which strata belong to the pre-Flood, Flood, and post-Flood periods by recognizing large-scale patterns or suites of criteria, will help us more fully understand the biostratigraphic patterns found within the rock record.

Keywords

Flood boundaries, Flood models, Flood evidences, Geologic column, Wyoming, Biostratigraphy, Criteria, Great Unconformity, Pre-Flood, Flood, Post-Flood, Green River Formation, Index fossils, Zone fossils

Introduction

Since the revival of modern Flood geology with the publication of *The Genesis Flood*, creationists have debated which rock strata mark the beginning and the end of the Flood. Whitcomb and Morris (1961) argued that most sedimentary rocks except the Pleistocene were deposited by the Flood, a view more recently championed by Holt (1996). Others have suggested that there is little or no surviving Flood record (Robinson, 2000; Tyler, 2006); that it is represented by uppermost Precambrian and Paleozoic rocks (Robinson, 1996); or that it is represented by uppermost Precambrian, Paleozoic, and Mesozoic rocks (Austin, Baumgardner, Humphreys, Snelling, Vardiman, & Wise, 1994). Most approaches have assumed it is appropriate to use chronostratigraphic units to define Flood boundaries. Very little thought has been given as to whether these units (defined by radioisotope dates and zone fossils) actually can (or should) be successfully used within a Flood model. Radioisotope dates and zone fossils may eventually prove useful in identifying various stages of the Flood, but criteria must first be established so this can be done confidently. Furthermore, once a boundary is established in a particular area, and zone fossils are identified, is it appropriate to extend the boundary to other areas and continents, using only these zone fossils? The method we propose should contribute to our understanding of these problems

In this paper, we take the approach that the pre-Flood, Flood, and post-Flood boundaries should primarily be identified by applying suites of criteria and recognizing widespread patterns. For example, we would not expect to find glacial, lacustrine and aeolian deposits being laid down during the Flood; instead, we would expect to find these kinds of deposits, in increasing abundance, following the Flood. However, during the Flood, we would expect to find marine deposits on the continents, global and regional unconformities, evidence of massive tectonic activity, mass-kill deposits, and deposits of unparalleled extent. We would not expect these features to be widespread before or after the Flood. We argue, that in identifying any particular rock unit as pre-Flood, Flood, or post-Flood, *suites of criteria* must be considered for a particular stratigraphic section. It is not one or two particular criteria that identify something as pre-Flood, Flood, or post-Flood, but instead an *entire suite of criteria.*

This model is illustrated by Figure 1. The chart is divided into three columns: pre-Flood, Flood, and post-Flood. Various criteria (not exhaustive) are listed along the left-hand side of the chart. The importance of each criterion is indicated horizontally through the three columns. The thickness of each horizontal line indicates the importance of the criterion during a particular time. In general, criteria that represent Flood processes are at the top, and those that
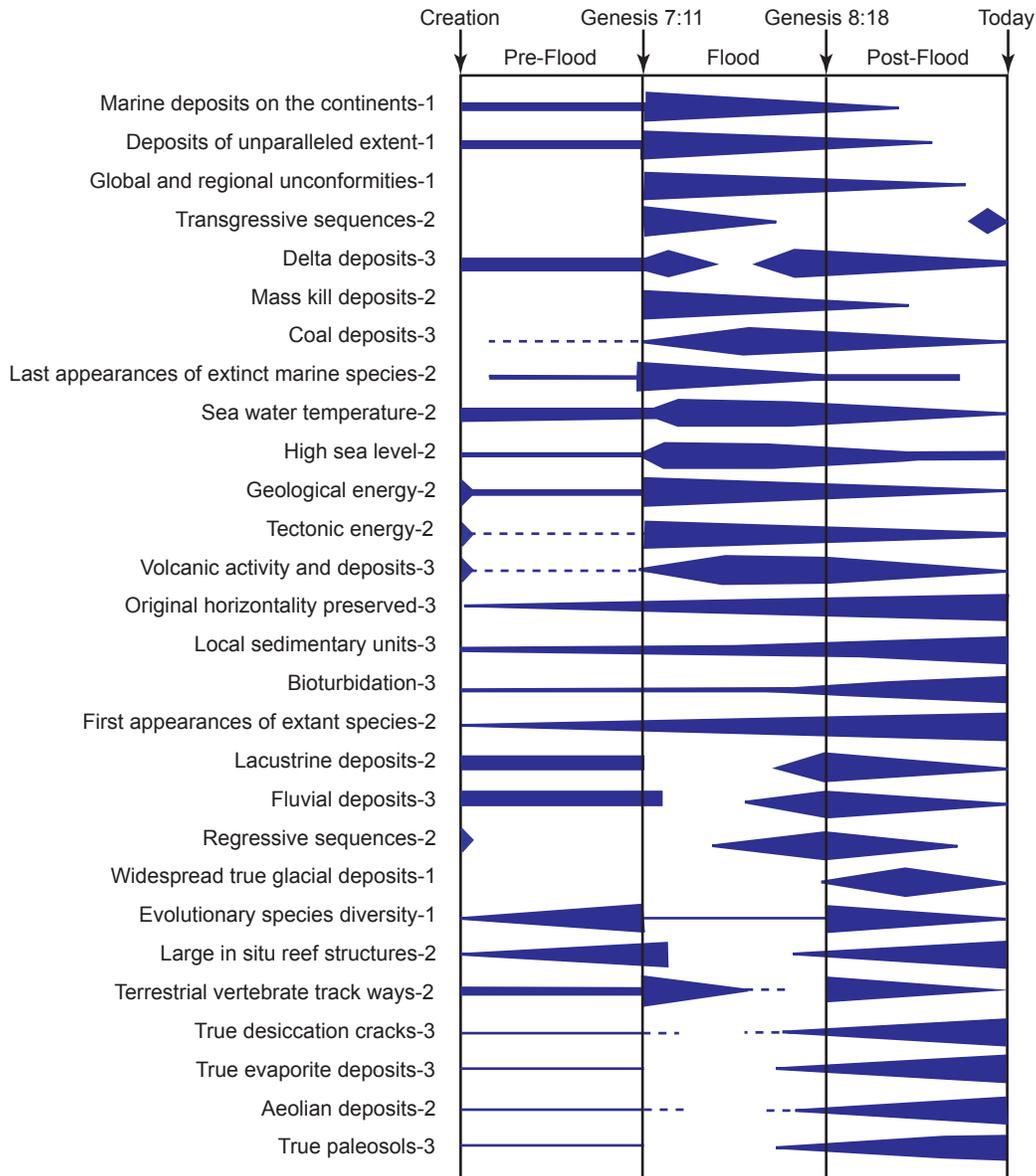
Figure 1. The thickness of a line indicates the relative importance of a particular process during a time period. The number following each criterion (1, 2, or 3) is a rank of how important we feel each criterion is within a Flood model (1 being the highest).

represent post-Flood processes are at the bottom. When examining a particular stratigraphic column, the researcher should look for these criteria as an aid to determining the section's placement within a young-age creation model. We consider some criteria more diagnostic than others, and have attempted to rank them accordingly (1, 2, or 3, with 1 being most important and 3 least important).

Application of this model is made using the lithostratigraphic section from Wyoming and vicinity (USA) as an illustration of how the criteria model should be used. Not only can this model be used to more confidently determine Flood boundaries, but it might be used as a test to see whether we can rely on chronostratigraphic units and/or zone fossils to

determine Flood boundaries. Properly understanding which strata belong to the pre-Flood, Flood, and post-Flood periods will help us better understand the biostratigraphic patterns found within the rock record.

The Biblical Record of Creation and the Flood

Any Creation-Flood model is dependent upon the author's underlying assumptions and view and interpretation of the biblical record. We take a literal young earth (~6,000 years) approach to Scripture. Approximately 1,700 years after the Creation, we believe the earth was deluged by Noah's Flood, leaving recognizable evidence of catastrophe in the rock record. Following is a brief outline of what we

think are the most important geological events that can be inferred from Scripture and which might be preserved in the geological record: (1) on the third day of the Creation week (Genesis 1:9–10) rock was created and/or uplifted to form the continental cratons. We suspect some of this rock still exists, albeit modified by subsequent events during Creation week and the Flood. We think Creation week rock may be represented by some or most of the igneous and metamorphic basement that often deeply underlies the richly fossiliferous sedimentary rock of the continents. We can see no Scriptural reason to exclude the possibility that unfossiliferous sediments were directly created early in Creation week. In addition, some unfossiliferous sediments may have formed as a result of tectonic activity on the third day. (2) After the Creation Week and before the Flood, sediments probably accumulated around the edges of the pre-Flood continent(s) forming deltas and other types of sedimentary deposits on the sea floor. Although much of this record was probably destroyed during the initial stages of the Flood, some may still exist. Scripture does not prohibit volcanic and tectonic activity before the Flood, although we think it was probably limited in energy and extent. (3) Geologic activity during the Flood begins with Genesis 7:11–12, which refers to the "breaking up of the fountains of the great deep" and the "opening of the floodgates of heaven." We are in agreement with the Catastrophic Plate Tectonics model which proposes that the Flood was primarily a tectonic catastrophe that began in the ocean basins and led to the transgression of ocean waters onto the continents (Austin et al., 1994). The water erupting from the fountains of the great deep was probably hot and, as it cooled and condensed, it would have fallen worldwide as an intense rain. Earthquakes and tsunamis resulted from the great tectonic activity in the ocean basins. Since the cores of the continental cratons are primarily granitic in composition, and lighter than the basaltic ocean crust, we believe the current land masses (albeit arranged very differently) were also the earth's pre-Flood land masses. We think that the sudden tectonic beginning of the Flood will be easier to recognize in the strata than the end of the Flood. Austin and Wise (1994) proposed criteria for recognizing this boundary in the Grand Canyon, and we think these criteria can be broadly applied. (4) Total (global) coverage of the earth's land masses with water occurred at some point during the Flood (Genesis 7:19), causing the extermination of all air-breathing, non-aqueous organisms (Genesis 7:21). While ocean water covered the continents, marine animals were transported and buried on the submerged continents. Pre-Flood floating forests were destroyed and buried within marine sequences, forming massive and widespread coal deposits (Wise,

2003b). Continental ecosystems were the last to be destroyed and buried, and the first to be eroded by post-Flood processes as the waters receded. (5) At the end of the Flood, Psalm 104:8 indicates that the mountains (land masses) rose up and the waters returned to the valleys (oceans). (6) The post-Flood era begins in Genesis 8:18 with Noah, his family, and the animals leaving the Ark. When reading the account of the sending out of the raven and dove in Genesis 8, one gets the sense that the Flood water receded gradually. For this reason, the Flood/post-Flood boundary may be gradational within the earth's strata. We picture Flood water receding much more slowly (perhaps over a period of years) compared to its sudden onset in Genesis 7:11. (7) Due to the tectonic uplift described in Psalm 104:8, large continental basins were probably created, making large temporary (and sometimes permanent) continental lakes and seas. Large rivers formed, cutting deep continental valleys and depositing a tremendous amount of sediment in the post-Flood oceans. (8) Perhaps the Rainbow Promise (Genesis 9:12–17) was given in part to encourage Noah and his family to disperse and fill the earth despite the probable post-Flood storms and tectonic readjustments that occurred. Perhaps God wanted Noah to be secure in knowing that post-Flood storms and tectonic activity would never again lead to worldwide inundation. (9) As the animals dispersed and filled the earth, Scripture implies that rapid intrabaraminic diversification took place (Wood, 2002). The purpose would be to fill and occupy new niches worldwide, according to God's command given in Genesis 9:1 and 9:7. (10) Widespread human fossils would only show up in the record once the dispersal from the Tower of Babel had taken place (Genesis 11). (11) Evaporation of the warm ocean water, along with post-Flood volcanic activity eventually caused continental glaciation. The glaciation was probably happening during the time of Job (about the same time as Abraham), since many references to snow, cold, and ice are found in this ancient book (for example, Job 37:9–10; 38:22–23, 29–30).

Criteria

Here we describe the criteria that we are proposing for the identification of Flood boundaries in the stratigraphic record. The reader should note, as previously stated, that we do not regard each of the criteria as of equal importance; rather, we consider some to be of greater significance than others. We would give more weight, for example, to the presence of marine deposits of unparalleled extent on the continents than to the presence of putative mud cracks or paleosols. Furthermore, we do not propose that these criteria should be applied *individually*; rather, we recommend that conclusions should only

be drawn based upon the application and evaluation of *multiple* criteria.

The horizontal lines in Figure 1 show the importance of each criterion during the pre-Flood time (Creation to Genesis 7:11), during the time of the Flood (Genesis 7:11–8:18) and during the post-Flood time (following Genesis 8:18). The thickness of each line indicates how extensive (or important) we think these criteria (or features) were on earth during these times. For example, *marine deposits on the continents* were probably not extensive in pre-Flood times, but certainly shallow shelves may have been covered with seawater, as they are today. The period is represented by a thin line on Figure 1 to indicate the possibility of some sedimentation during this period. During the time of the Flood these deposits are assumed to have become much more extensive, so the line dramatically widens. As the Flood waned, these deposits became less important and finely diminished to the conditions today, as represented by the tapering wedge in Figure 1. The reader must realize that the lines representing the criteria in Figure 1 are merely indicative, not necessarily drawn to scale, and may need to be modified with future work.

A rank of "1" is given if we feel the criterion is indicative of a particular period of earth history. For example, we believe that marine deposits on the continents were primarily a characteristic of the Flood and glacial deposits were only formed in post-Flood times. A rank of "2" is given if we feel a criterion is secondary in importance, or if it significantly crosses two periods of earth history. For example, we might find transgressive sequences during the Flood and during melting of glacial ice. A rank of "3" is given if we feel the criterion is tertiary in importance, or if it crosses all three periods of earth history. For example, delta deposits may not be particularly indicative of any period of earth history. They could have formed from pre-Flood rivers entering the ocean; large rivers initially draining Flood water from the continents; or by post-Flood rivers. Putative paleosols are given a rank of "3" because of uncertainties concerning their recognition and true interpretation. Ranks are shown on Figure 1, following each criterion.

Marine deposits on the continents (rank = 1)

Since the Flood appears to have been a transgressive event, proceeding from the oceans onto the land (Austin et al., 1994), we would expect Flood-deposited sequences to be characterized by thick marine sediments blanketing the continents. It is possible, however, that some marine sedimentary sequences are the result of deposition in the extensive, shallow, epeiric oceans that may have surrounded the pre-Flood continents. We rank this as "1" based on biblical considerations. The Flood was an event in which the oceans covered the continent(s) (Genesis 8:19–20), therefore we would expect evidence of marine inundation on the land. We recognize the marine status of some units is debated because of the lack of marine fossils (like the Coconino and Navajo Sandstones) and therefore the application of this criterion needs to be used carefully.

Deposits of unparalleled extent (rank = 1)

Since the Flood was a global event, we would expect Flood-deposited sequences to be much more extensive (global, continental) than those typically laid down in modern oceans, rivers and lakes (local, regional). Some widespread deposits may also have formed, however, during the regression of waters from the continents on Day Three of Creation week and in the pre-Flood epeiric oceans. We rank this as "1" because we believe global processes were of primary importance during the Flood, producing deposits that are more widespread and uniform than those deposits that would be found today.

Global and regional unconformities (rank = 1)

Since the Flood was a global event, and would have involved both depositional and erosive phases, we would expect Flood-deposited sequences to be characterized by unconformities of global and regional extent. Very widespread erosion surfaces would also be expected to have formed in association with the recession of the ocean waters from the continents at the end of the Flood and with the intense precipitation predicted by models of the early post-Flood climate (Vardiman, 2003). We rank this as "1" because we believe that processes during the Flood were particularly likely to generate worldwide and regional-scale unconformities.

Transgressive sequences (rank = 2)

Since the Flood involved the global transgression of ocean water onto the continents, we would expect the early Flood record to be characterized by a stratigraphically-younging trend from shallow-water clastic facies (like sandstone) to deeper-water fine-grained facies (like carbonate). A minor transgressive sequence might also be expected as a result of the melting of the post-Flood ice sheets. We rank this as "2" because transgressive events would have been important during the Flood (especially early on) and during the melting of glacial ice after the Flood, although the initial Flood transgression(s) would have left much more extensive deposits.

Delta deposits (rank = 3)

Since we know that rivers existed before the Flood, at least in the vicinity of Eden (Genesis 2:10–14) and by inference elsewhere, delta deposits—wedge-

shaped packages of sediment formed where rivers flow into an ocean or lake—could have been formed at that time. Deltaic sediments could have continued to accumulate during the initial phases of the Flood but were probably terminated as the Flood waters reached their maximum depth. As the waters drained off the continents at the end of the Flood, deltaic sedimentation would have been resumed and would have continued into the post-Flood period, with declining rates of accumulation as the earth dried out and the sediment-carrying capacity of streams and rivers waned. We rank this as "3" since delta deposits might be expected everywhere in the record, except at the Flood's zenith. The largest deltas probably formed at the beginning of the Flood and at the end of the Flood as rivers drained the freshly exposed continents.

Mass-kill deposits (rank = 2)

Since the Flood involved the rapid accumulation of sediments under catastrophic conditions, Flood-deposited sequences would be expected to record the death and burial en masse of entire organismal populations. Mass-kill deposits are also likely to have been associated with the residual catastrophism following the Flood, but with declining frequency and geographical extent over time. We rank this as "2" because mass-kill deposits may have occurred before and after the Flood, although we believe they would have been more prevalent during the Flood.

Coal deposits (rank = 3)

Since the Flood involved the global transgression of ocean water onto the continents, Flood-deposited sequences would be expected to record the destruction and burial en masse of floating, coastal and terrestrial vegetation. Elevated temperatures and pressures associated with burial might subsequently transform some of this vegetation into coal. After the Flood there would have been additional opportunities for coal formation, associated with the burial of vegetation rafts left over from the Flood and the burial of new-growth vegetation, but with declining frequency and geographical extent over time. We rank this as "3" because coal deposits may have formed at any period of earth history, although they were probably most important during the Flood.

Last appearances of extinct marine species (rank = 2)

Since most marine extinctions are likely to have occurred directly as a result of the global Flood, due to the non-representation of these organisms on the Ark, the last appearances of extinct marine species would be expected to occur predominantly in Flood-deposited sediments. However, we give this a rank of "2" because some marine extinctions may have occurred after the Flood, and some marine extinctions may be uncertain (that is, the large number of "living fossils" that have been found). However we believe most marine extinctions probably occurred during the Flood.

Sea water temperature (rank = 2)

Since the Flood was associated with extensive tectonic and volcanic activity, we would expect the average ocean temperature to have risen significantly (a few tens of degrees) by the end of the event. After the Flood, the oceans would have gradually cooled by evaporation with average ocean temperatures eventually dropping to today's 4°C (Oard, 1990). We would therefore expect indicators of warmth to be associated with Flood-deposited sequences and a trend of declining temperatures to be associated with post-Flood sediments. In many cases, warmth may be indicated by extensive carbonate deposits, since calcium carbonate is usually soluble in cold water (we recognize other factors are also involved in carbonate precipitation). We give this criterion a rank of "2" because high seawater temperatures were probably present both during and after the Flood, tapering to today's values.

High sea level (rank = 2)

The formation of hot, buoyant ocean floor during the Flood appears to have resulted in a significant (several kilometers) rise in sea level, sufficient to cause the global inundation of the continents with ocean water. We would therefore expect Flood-deposited sequences to be associated with a high stand of sea-level, declining into the post-Flood period as the new ocean floor cooled and subsided, allowing the recession of the Flood waters into the deepening ocean basins. A much smaller fall and rise of sea level would also be expected as a result of the growth and subsequent melting of the post-Flood ice sheets (Oard, 1990). We rank this as "2" because sea levels were probably high at the Flood's end, gradually reaching today's levels.

Geological energy (rank = 2)

Since the Flood was a unique global event, apparently involving the complete overturn of the earth's mantle and the restructuring of the earth's crust, it must have involved the expenditure of geological energy orders of magnitude greater than any subsequent event. We would expect Flood-deposited sequences to be associated with high energy levels and post-Flood sequences to be characterized by a gradual decline over time to present-day levels. Geologically energetic events would include land slides, turbidites, mass flows, etc. High energy levels would also have been

associated with the regression of waters from the continents on Day Three of Creation week. We believe geologically energetic events probably continued into the post-Flood time and those events might be difficult to distinguish from those that happened during the Flood, so we rank this as "2."

Tectonic activity (rank = 2)

Since the Flood was a unique global event, apparently involving the complete overturn of the earth's mantle and the restructuring of the earth's crust, it must have involved levels of tectonic activity greater than any subsequent event. The tectonic activity associated with post-Flood catastrophism would gradually have declined to present-day levels. Tectonic activity would also have been associated with the uplift of the continents on Day Three of Creation week. Since tectonic activity was probably most prevalent during the Flood, but probably continued into post-Flood times, we rank this as "2."

Volcanic activity and deposits (rank = 3)

Since the Flood was a unique global event, apparently involving the overturning of the earth's mantle and the restructuring of the earth's crust, it must have involved levels of volcanic activity greater than any subsequent event. The volcanic activity associated with post-Flood catastrophism would gradually have declined to present-day levels. Low levels of volcanic activity may have occurred before the Flood, perhaps associated with hydrothermal spring environments in which certain pre-Flood organisms (for example, stromatolites and hyperthermophilic bacteria) might have thrived (Wise, 2003a). Although we believe volcanic activity was most prevalent during the Flood, evidence for it (ash beds, lava flows) might be preserved during any period of earth history. Ash beds might not be as well-preserved during the Flood because ash may have been easily mixed into other sediments during aqueous turbulence. Therefore, we might expect more ash horizons following the Flood than during the Flood. We rank this as "3" because of the possibility of volcanic deposits occurring during any period of earth history.

Original horizontality preserved (rank = 3)

Sediments are usually laid down in horizontal layers parallel to the surface on which they are being deposited. Over time, however, there is the potential for layers to be subjected to tectonic forces that disturb their original horizontality. All other things being equal, the more time that passes the more likely it is that sediments will be disturbed in this way. We would therefore expect pre-Flood sediments to be more disturbed than Flood layers, and Flood layers more than post-Flood layers. We

rank this as "3" because original horizontality is dependent upon tectonic activity. Not all areas on earth have experienced equal amounts of tectonic activity. However, if folded marine sedimentary rocks lie below relatively horizontal terrestrial deposits, we think this is of secondary (rank = 2) or even primary (rank = 1) importance in our model. Of course this is dependent upon being able to clearly distinguish marine and terrestrial rocks.

Local sedimentary units (rank = 3)

As the Floodwaters receded, and in the centuries after the Flood, sedimentation patterns would have become much more localized and confined to basins. Although localized sedimentary units are likely to have been formed during the Flood as well, we would expect them to particularly dominate late Flood and post-Flood sedimentary sequences which formed during or following the recession of the waters. Since deposits of local extent may occur at any time in earth history, we rank this criterion as "3," although we would expect local deposits to have become more prominent as the Floodwaters regressed and deposits were no longer affected by global marine processes.

Bioturbation (rank = 3)

Since the Flood involved the rapid accumulation of sediments without the passage of long periods between the deposition of individual layers, we would expect extensively bioturbated horizons, with the resultant disruption of internal stratification and sedimentary structures, to be less common in Flood-deposited sediments. Before and after the Flood, as more time became available between depositional events, we would expect bioturbation to become much more abundant. We recognize that bioturbation could have occurred during the Flood on select horizons (and vertically within beds), but we expect the more slowly deposited post-Flood sediments to contain much more evidence of biological disruption. We rank bioturbation as "3" because it may have occurred at any time during earth history, although we think its preservation potential is highest in post-Flood times.

First appearance of extant species (rank=2)

Since the post-Flood period was apparently characterized by rapid intrabaraminic diversification (Whitmore & Wise, 2008; Wood, 2002), we would expect the post-Flood sediments to preserve a progressively higher percentage of modern species as we move stratigraphically higher in the sequence. However we cannot rank this as primary importance because we believe some extant (living) species may be represented in Flood sediments. We give this a rank of "2."

Lacustrine deposits (rank = 2)

Since the Flood involved the inundation of the continents with water, we would expect true lake deposits to be absent from Flood-deposited sequences. However, models suggesting that the early post-Flood climate was much wetter than today (Vardiman, 2003) might lead us to expect stratigraphic evidence of extensive post-Flood lakes, even in regions that are now arid. Furthermore, lake deposits could have been formed before the Flood. We rank this as "2" because lacustrine deposits might occur both before and after the Flood. Additionally, they may have straddled the Flood/post-Flood boundary as the Floodwaters retreated. Thus, they may be of primary (rank = 1) importance in identifying post-Flood strata. In identifying lacustrine deposits, see Whitmore's caution (2006a).

Fluvial deposits (rank = 3)

Since we know that rivers existed before the Flood, at least in the vicinity of Eden (Genesis 2:10–14) and by inference elsewhere, fluvial deposits could have been formed at that time. Fluvial sediments could have continued to accumulate during the initial phases of the Flood but were probably terminated as the Floodwaters reached their maximum depth. As the waters drained off the continents at the end of the Flood, fluvial sedimentation would have been resumed and would have continued into the post-Flood period, with declining rates of accumulation as the earth dried out and the sediment-carrying capacity of streams and rivers waned. We rank this criterion as "3" since fluvial deposits may occur at nearly every point in earth history, except during the zenith of the Flood.

Regressive sequences (rank = 2)

Since the Flood appears to have concluded with a major regression of the Floodwaters into the deepening ocean basins, we would expect the late Flood record to be characterized by a stratigraphically-younging trend from deep-water fine-grained facies (like carbonate) to shallower-water clastic ones (like sandstone). However, we note that marine regressions are generally poorly represented by sediments in the stratigraphic record and the end-Flood regression may instead be marked by a major erosive unconformity on which more localized post-Flood deposits may be resting. We rank this criterion as "2" because we might expect to see regressive sequences (if preserved) at several places in earth history. The most regionally extensive sequences would occur as the Floodwaters retreated.

Widespread true glacial deposits (rank = 1)

Since the Flood involved the global inundation of the continents with ocean water, and since ocean temperatures were likely to have been high during the Flood, we would not expect any widespread glacial sediments associated with Flood-deposited sequences. After the Flood, the oceans would have gradually cooled by evaporation and we would expect post-Flood sequences to be characterized by declining temperatures and the growth of extensive ice sheets over the mid- and high-latitude continents. We rank this criterion as "1" since we think there was only one period of extensive glaciation that happened in post-Flood times. Conventional geology interprets some diamictites as glacial deposits within what we believe are pre-Flood and Flood sequences, but we agree with Oard (1997) who has questioned these claims.

Evolutionary species diversity (rank = 1)

Since the Flood lasted about a year, we would not expect to see any interspecific transitional fossil series in Flood-deposited sediments, with the possible exception of organisms with life cycles much less than a year (Wise, 1989). We rank this criterion as "1" since we expect intrabaraminic transitional sequences to be a major paleontological theme in post-Flood sediments.

Large in situ biogenic structures (rank = 2)

Since the Flood involved the rapid accumulation of sediments without the passage of long periods between the deposition of individual layers, we would not expect much time to be available for the growth of large reefs or other truly in situ biogenic structures. However, towards the end of the Flood and continuing into the post-Flood period, as more time became available between depositional events, the growth of in situ biogenic structures would be expected to become more common. Small in situ deposits might be possible during the Flood. We rank this criterion as "2" because some large reef deposits may have started in late-Flood times and extended into the post-Flood era.

Terrestrial vertebrate trackways (rank = 2)

Since the Flood brought about the destruction of all air-breathing land vertebrates outside the Ark (Genesis 7:21–23), we would expect trackways of living air-breathing land vertebrates to be found only in early Flood sediments (before they all perished) or in post-Flood sediments following the migration and dispersal of air-breathing land vertebrates from the Ark. We recognize, however, that there is little consensus on precisely when during the Flood the air-breathing land vertebrates perished (40 vs. 150 days). We also recognize the difficulties inherent in distinguishing the trackways of air-breathing land vertebrates from those of aquatic or semi-aquatic

vertebrates that may have survived in numbers outside the Ark. Recently documented swimming tracks (Ezquerra, Doublet, Costeur, Galton, & Perez-Lorente, 2007; Ishigaki, 1989) suggest that even some dinosaurs may have been able to survive in the Flood waters. We rank this criterion as "2" because *terrestrial* vertebrate trackways are an important Scriptural indicator of the height of Flood waters. However, trackways may occur during any period of earth history, except during the Flood's zenith (although even then aquatic vertebrates may have left underwater tracks).

True desiccation cracks (rank = 3)

Since the Flood involved the inundation of the continents with water, we would expect true desiccation cracks to be rare in Flood-deposited sediments. We note, however, that modern desiccation cracks have been observed to form within a single tidal cycle (Dionne, 1974), suggesting that some may have formed where sediments were briefly exposed subaerially during the Flood. We also note that other types of cracks (syneresis, substratal and tectonic cracks) may be mistaken for true desiccation cracks (Whitmore, in press). We would expect desiccation cracks to be far more abundant in pre- and post-Flood sediments. We give this a rank of "3" because desiccation cracks can be mimicked by other features and can be difficult to identify (Whitmore, in press). True desiccation cracks would be expected primarily in post-Flood sediments.

True evaporite deposits (rank = 3)

Since the Flood involved the inundation of the continents with water, we would expect true evaporite deposits (those formed by the slow evaporation of sea water) to be absent from Flood-deposited sequences. We note, however, that salt deposition from supersaturated brines can take place without evaporation and may mimic true evaporite deposits (Hovland, Rueslatten, Johnsen, Kvamme, & Kuznetsova, 2006). By contrast, we would expect true evaporite deposits to characterize pre- and post-Flood sequences. We rank this as "3" because true evaporite deposits may be difficult to distinguish between those of hot-water brines.

Aeolian deposits (rank = 2)

Since the Flood involved the inundation of the continents with water, we would expect wind-blown deposits to be rare in Flood-deposited sequences. We note, however, that subaqueously-deposited sediments can be mistaken for wind-blown sediments and that genuine aeolian deposits may have formed on briefly exposed subaerial surfaces during the Flood. This may have been especially true during the recessive phase of the Flood when a powerful wind began to dry up the land (Genesis 8:1). Nevertheless, wind-blown sediments would be expected to be significantly more abundant in pre-Flood and, especially, post-Flood sequences. We rank this as "2" because wind-blown sediments should primarily be found in post-Flood sequences, but have the potential to be present elsewhere.

True paleosols (rank = 3)

Since the Flood involved the rapid accumulation of sediments without the passage of long periods between the deposition of individual layers, we would not expect the development of true soil horizons in Flood-deposited sediments. We note, however, that the chemical alteration and diagenesis of sediments can mimic true paleosols (Oard, 1990). After the Flood, as more time became available between depositional events, weathered horizons and paleosols would be expected to become more abundant. We rank paleosols as a "3" because they are difficult to diagnose and could potentially be present during at least two of our time divisions (Walker, 2003).

The Lithostratigraphic Column of Wyoming

A typical lithostratigraphic column of western Wyoming (Table 1) is presented as an example of how to apply our criteria model. Summaries of lithology, sedimentary structures, paleontology, extent, thickness, etc., can be found in the Appendix. Additional figures illustrating some of the rocks of the section can be found in the Appendix. In general, the sedimentary column rests on a crystalline basement complex of igneous and metamorphic rock. A thick series of sedimentary rocks unconformably rests on these basement rocks. Most of the rocks in the sedimentary series are easily identifiable as marine. There are some exceptions, especially rocks containing dinosaur remains and those conventionally interpreted as aeolian. This entire sedimentary series is then folded, and eroded. Relatively flat-lying lacustrine and fluvial deposits occur within basins floored by the folded and faulted sedimentary rock (Figure 2). Glacial and volcanic deposits overlie the lacustrine deposits.

Discussion and Application of the Model

Despite many attempts to define the beginning and end of the Flood in the stratigraphic record, there has remained a marked lack of consensus on these matters among young-age creationists. This is particularly true of the Flood/post-Flood boundary, although, to a lesser extent, it also applies to the pre-Flood/Flood boundary. One difficulty facing us is that the Flood/post-Flood boundary is not easily defined geologically. There are biblical reasons to believe that

Table 1. Occurrence of criteria in the Wyoming lithostratigraphic column. The generalized geologic column from Wyoming is on the left. The oldest rocks are on the bottom (the crystalline basement rocks) and the youngest rocks are on the top (volcanic and glacial deposits). Our various criteria are along the top of the table from left to right. In our brief survey of these formations, if we found a particular formation exhibited a particular criterion, we placed an "x" in the appropriate bin. If a particular criterion is questionable for a formation we have used a "?." The grouping of "x"s on the left side indicates Flood deposits and the grouping of "x"s in the upper right indicates post-Flood deposits. From our preliminary data, we would place the Flood/post-Flood boundary somewhere in the Lance or Fort Union Formation.

	Marine deposits on the continents, r=1	Deposits of unparalleled extent, r=1	Global and regional unconformities, r=1	Transgressive sequences, r=2	Delta deposits, r=3	Mass-kill deposits, r=2	Coal deposits, r=3	Last appearances of extinct marine species, r=2	Seawater temperature, r=2	High sea leve, r=2	Geological energy, r=2	Tectonic activity, r=2	Volcanic activity and deposits, r=3	Original horizontality preserved, r=3	Local sedimentary units, r=3	Biotubation, r=3	First appearance of extant species, r=2	Lacustrine deposits, r=2	Fluvial deposits, r=3	Regressive sequences, r=2	Widespread true glacial deposits, r=1	Evolutionary species diversity, r=1	Large in situ reef structures, r=2	Terrestrial vertebrate trackways, r=2	True desiccation cracks, r=3	True evaporite deposits, r=3	Aeolian deposits, r=2	True paleosols, r=3
Glacial Deposits																					x							
Volcanics (Yellowstone)													x															
Bridger Formation					x	x							x	x	x	x	x	x	x			x						
Green River Formation				x	x	x							x	x	x	x	x	x	x			x	x	x	x	x		x
Wasatch Formation					x	x							x	x	x	x	x	x				x						
Fort Union Formation			x	x							x	x	x	x		x	x	x	x	x								x
Lance Formation	x	x			x	x	x	x			x		x					x	x						x			
Mesaverde Formation	x	x	x	x	x		x			x			x				x		x	x				?				?
Baxter Shale	x	x		x						x																		
Frontier Formation	x	x		x				x											x									
Mowry Shale	x	x											x															
Thermopolis Shale	x	x	x							x																		
Cloverly Formation													x					x	x									
Morrison Formation	x	x			x	x	x			x	x		x			x		x	x						x		?	
Sundance Formation	x	x	x							x						x										?		
Nugget Sandstone	?	x																?										
Chugwater Group	x	x		x														?	x									
Dinwoody Formation	x	x																										
Phosphoia Formation	x	x						?	x																			
Tensleep Sandstone	?	x																										
Amsden Formation	x									x																		
Madison Limestone	x	x				x			x	x																		
Big Horn Dolomite	x	x							x	x																		
Gallatin Limestone	x	x	x			x			x	x													?					
Gros Ventre Group	x	x	x			x		x	x							x							?					
Flathead sandstone	x	x	x	x				x		x	x					x												
Crystalline basement rocks			x										x	x														

it may be gradational in any particular region and that its placement may even vary somewhat from region to region. According to Genesis 7:11, the Flood began with a global geological event: "the breaking up of all the fountains of the great deep." However, this is not the case with the end of the Flood, which seems to be marked by the slow drying of the ground in the vicinity of the landing place of the Ark

Figure 2. An west-east cross section through Fossil Basin, southwestern Wyoming, modified from Rubey, Orieal & Tracey (1975). Fossil Butte is near the center of the cross section. Note the underlying rocks are folded and faulted. The overlying rocks of the Wasatch and Green River Formations lie relatively undisturbed and rest unconformably in the basin that formed as the area was uplifted. Most of the rocks below Wasatch and Green River are marine and geographically widespread. The underlying geology is well-known because of petroleum exploration. Compare with Figure 8.

(Genesis 8:13). The biblical text does not inform us how quickly the Flood waters receded in other areas. Slow tectonic rebound and other post-Flood tectonic adjustments may have kept some regions underwater for years.

Another complicating factor is the residual catastrophism that probably persisted for some centuries after the Flood. It may be difficult in some cases to distinguish this from the catastrophism associated with the Flood itself. We know that this issue, especially as it applies to the rock record of the western United States, has been of great concern to some creationists, for example, Oard (1996, 2006). Tectonic events (Baumgardner, 2005; Ollier & Pain, 2000), volcanic activity (Austin, 1998) and climatic instability (Vardiman, 2003) were probably all involved in this post-Flood activity. Hypercanes were likely to have been particularly destructive in the immediate post-Flood years and, during the ice age, catastrophic subglacial floods may have also been a factor (Martini, Baker, & Garzon, 2002; Oard, 2004). We believe that a significant amount of post-Flood catastrophism definitely occurred, albeit on a much smaller scale than that associated with the Flood. We readily acknowledge, however, that the mechanisms and results of this catastrophism need much more study.

As already stated, our approach to identifying the Flood boundaries in the rock record has been to propose and apply an entire suite of criteria, rather than rely on single evidences. We recognize, of course, that some of our criteria are of greater significance than others and have tried to evaluate them accordingly. Obviously, this is a subjective evaluation on our part and may be open to criticism. Other young-age creationists may disagree with us concerning the relative importance of our criteria and may be able to suggest other criteria we have not included. In describing our chosen criteria, we have made some attempts to justify the ranking we have applied, noting uncertainties and caveats in the interpretation of geological features as necessary. At some point, it may be possible for a numerical scoring system to be devised to facilitate the ranking and evaluation of our criteria which would help to reduce the subjectivity involved.

In Figure 1, we have broadly separated our criteria into those indicative of Flood (upper part) and post-Flood (lower part) processes. In Table 1 we have then sought to summarize our application of the criteria to the lithostratigraphic column of western Wyoming. Various locations could have been chosen to show how our model should be applied. Wyoming was chosen because it has been well studied, its rocks are well exposed and previous work and familiarity by the primary author in this area (Whitmore, 2003,

2006 a, b, c). The lithostratigraphic units are listed vertically in Table 1, with the proposed criteria along the top. An "x" is placed in each bin of the table where a particular criterion applies to each formation or group. A "?" is given if the feature is ambiguous or if we question its occurrence. The "tick mark table" is intended to help organize the data from the many formations and to assist the recognition of important trends. Unfortunately, what we believe are pre-Flood rocks (especially sedimentary ones) are not well exposed in this area. However, we believe the rocks that are exposed serve to adequately demonstrate how to use our criteria model. The same method can be applied to other areas with any sequence of rocks.

Several trends can be recognized when considering Figure 1, Table 1, and the lithostratigraphic column of Wyoming: Marine deposits are an important and almost exclusive component of the column until the Mesaverde and Lance Formation are reached. Here, some of the deposits are marine, but many are interpreted as continental. Continental and regional deposits seem to become dominant *after* the deposition of the Lance. This is very clear when examining depositional patterns of equivalent formations in the *Geologic Atlas of the Rocky Mountain Region* (Figure 3). After the deposition of the Lance, the sediments also become extremely localized in nature. Furthermore, regional unconformities are more important lower
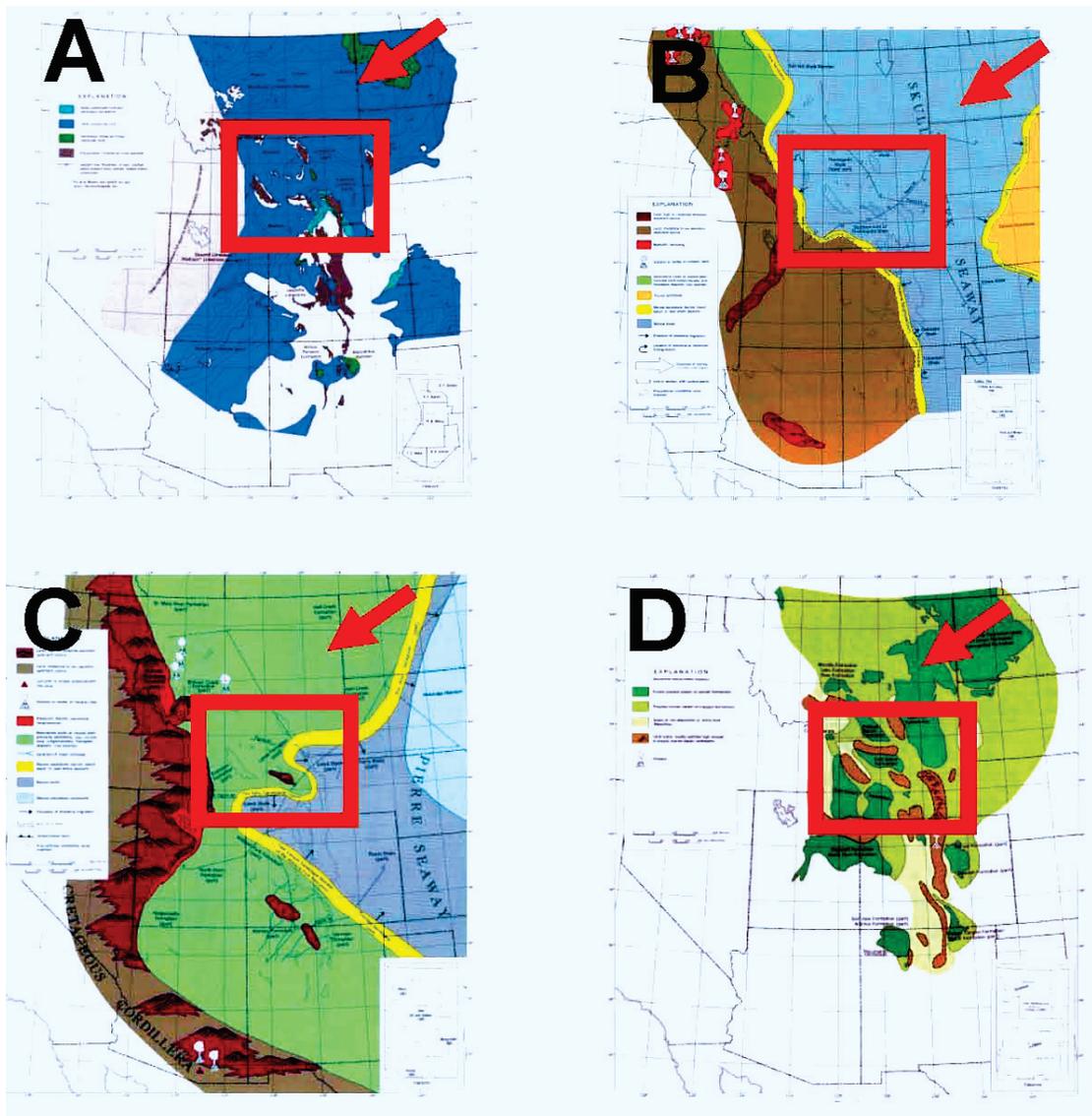
Figure 3. Maps showing changes that take place in aerial depositional extent of formations during A-deposition of the Madison Formation, B-deposition of the Thermopolis Shale, C-deposition of the Lance Formation, and D-depositiion of the Fort Union Formation. Formations indicated by red arrows. The state of Wyoming is highlighted in red. Note the aerial extent of deposition changes rapidly from C to D. This is also a change from dominantly marine to dominantly non-marine. Figures modified from the *Geologic Atlas of the Rocky Mountain Region*, 1972: A—Craig, p. 105; B—McGookey, p. 200, C—McGookey, p. 225; D—Robinson, p. 237.

in the section than higher in the section. In fact, the strata of the western United States have been divided up into "sequences" primarily based on major regional unconformities, transgressions and regressions (Sloss, 1988). Perhaps the Flood in this region was much more dynamic than a simple rise and fall of the Flood waters would suggest. Deltas, alluvial plains, and coastal sedimentary features are very common within the Mesaverde group (Roehler, 1990). Note that Figure 1 shows a predicted spike in delta activity toward the end of the Flood. In Wyoming, sea level seems to have remained high until Lance time; the Baxter, Mesaverde and Lance all have marine deposits within them. After this, however, no more marine deposits occur. Other trends can be examined, but we interpret these trends as evidence that the Flood waters were retreating during Baxter/Mesaverde/Lance time. In the sediments above the Lance, we see many indicators of terrestrial sedimentation, indicating a cessation of Flood processes in this region.

Comparing the data from the Appendix with Figure 1 and Table 1, we note that many of the features found in the Lance, Fort Union, Wasatch, Green River and Bridger Formations fall in the lower half of Figure 1. In Table 1, we perceive that a shift in "x's" takes place, near the top of the table. Instead of most of the "x's" falling on the left of the table, they begin to fall on the right side of the table. We interpret this shift as the end of Flood processes in Wyoming. The shift is a transitional one, not an immediate boundary like the unconformity under the Flathead Sandstone. We don't know precisely how this shift correlates to Genesis 8:18, when Noah and the animals got off the Ark. We do, however, believe that the extensive mammal radiations represented in the deposits of the Fort Union and succeeding formations, especially in the Green River Formation, must post-date Genesis 8:18 (see Whitmore & Wise, 2008). These deposits exhibit many terrestrial features and yield apparently monobaraminic stratomorphic fossil series (Cavanaugh, Wood, & Wise, 2003).

We conclude, therefore, that in our Wyoming section, the Flood/post-Flood boundary falls approximately during Lance to Fort Union Time (the Cretaceous/ Tertiary boundary occurs after the Lance). This conclusion represents a significant modification of the position previously expressed by Garner (1996a, 1996b). However, it is consistent with the preliminary conclusion of Austin et al. (1994). Based on our criteria, we picture the end of the Flood in Wyoming as follows. The last marine water gradually receded as the Rocky Mountains were uplifted, leaving deposits like the Baxter, Mesaverde and Lance Formations. As the mountains were uplifted (Psalm 104:8), large streams would have formed fluvial plains and deltas. Tectonic readjustments continued to cause catastrophic earth movements. Associated with the uplift, local and regional basins formed, leading to the deposition of the lacustrine and fluvial sediments found in the upper part of the Wyoming section. After the basins filled, rivers continued to leave fluvial deposits above the lacustrine sediments.

It is important to state that we do not accept conventional time scales and depositional analogues for the post-Flood sediments. We see Wyoming as a very dynamic place following the Flood. When we mention fluvial plain and lacustrine deposition, for example, we do not have in mind precisely equivalent environments today. We envisage deposits accumulating very quickly and environments changing very rapidly.

Finally, we suggest that attempts are made to apply our model in other localities. A logical place to use this model next might be the Colorado Plateau. A number of the formations in Wyoming, or their correlatives, are also present there. The model could also be extended to the central and eastern United States and to other continents. Once our model has been applied in various regions, attempts can then be made to correlate the identified Flood boundaries. Based on field evidence from around the world, we believe that there are consistent biostratigraphic and lithostratigraphic patterns that need to be explained within any successful Flood model and we accept, in principle, that correlations can be made. We do not think that this should surprise Flood geologists because a global event would surely be expected to leave a global signature or signatures. In fact, we believe that these lithostratigraphic and biostratigraphic patterns will yield important information about specific phases and/or events within the global Flood, if only we can interpret them correctly. Consider, for example, the transgressive sequence of sandstone/shale/carbonate that is commonly found stratigraphically above the crystalline basement rocks of the continents (Ager, 1983). This seems to mark a uniquely widespread event, namely the beginning of the Flood. Our expectation is that units like this will turn out to be broadly time-equivalent across the world, although we agree that the issue of time-equivalence deserves more thought and discussion by young-age creationists. We believe that our model may have some utility in helping us think through such issues.

Concluding Remarks

Determining the stratigraphic position of the Flood boundaries is undoubtedly a complex matter; however, our hope is that models such as the one we have proposed in this paper may lead us all to more carefully examine the rocks and defend our chosen boundaries using suites of criteria. We believe that the application of our model to many places around the

world will help us test the various hypotheses proposed to date for the location of the Flood boundaries and may even help Flood geologists approach a consensus on this thorniest of issues.

References

Ager, D.V. (1983). *The nature of the stratigraphical record* (2nd revised ed.). London: Macmillan Press.

Austin, S.A. (1998). The declining power of post-Flood volcanoes. *Institute for Creation Research, Impact #302*, i–iv.

Austin, S.A., Baumgardner, J.R., Humphreys, D.R., Snelling, A.A., Vardiman, L., & Wise, K.P. (1994). Catastrophic plate tectonics: A global flood model of earth history. In R.E. Walsh (Ed.), *Proceedings of the third international conference on creationism* (pp. 609–621). Pittsburgh, Pennsylvania: Creation Science Fellowship.

Austin, S.A., & Wise, K.P. (1994). The pre-Flood/Flood boundary: As defined in Grand Canyon, Arizona and eastern Mojave Desert, California. In R.E. Walsh (Ed.), *Proceedings of the third international conference on creationism* (pp. 37–47). Pittsburgh, Pennsylvania: Creation Science Fellowship.

Baumgardner, J.R. (2005). Recent rapid uplift of today's mountains. *Institute for Creation Research Impact #381*, i–iv.

Bradley, W.H., & Eugster, H.P. (1969). Geochemistry and paleolimnology of the trona deposits and associated authigenic minerals of the Green River Formation of Wyoming. *U.S. Geological Society Professional Paper, 496-B*, 1–71.

Brown, J.L. (1993). Sedimentology and depositional history of the Lower Paleocene Tullock Member of the Fort Union Formation, Powder River Basin, Wyoming and Montana. *U.S. Geological Survey Bulletin, 1917 L*, 1–42.

Buchheim, H.P. (1994). Paleoenvironments, lithofacies and varves of the Fossil Butte Member of the Eocene Green River Formation, Southwestern Wyoming. *Contributions to Geology, University of Wyoming, 30*(1), 3–14.

Buchheim, H.P., & Eugster, H.P. (1998). Eocene Fossil Lake: the Green River Formation of Fossil Basin, southwestern Wyoming. In J.K. Pitman & A.R. Carroll (Eds.), *Modern and ancient lake systems* (pp. 191–208). Salt Lake City: Utah Geological Association, Guidebook 26.

Cavanaugh, D.P., Wood, T.C., & Wise, K.P. (2003). Fossil Equidae: A monobaraminic, stratomorphic series. In R.L. Ivey, Jr. (Ed.), *Proceedings of the fifth international conference on creationism* (pp. 143–153). Pittsburgh, Pennsylvania: Creation Science Fellowship.

Cavaroc, V.V., & Flores, R.M. (1991). Red beds of the Triassic Chugwater Group, southwestern Powder River Basin, Wyoming. *U.S. Geological Survey Bulletin, 1917-E*, 1–17.

Chadwick, A., Spencer, L., & Turner, L. (2006). Preliminary depositional model for an Upper Cretaceous Edmontosaurus bonebed. *Journal of Vertebrate Paleontology, 26*(3-suppl.), 49.

Chisholm, W.A. (1963). The petrology of Upper Jurassic and Lower Cretaceous strata of the western interior. In G.C. Cooper, D.F. Cardinal, H.W. Lorenz & J.R. Lynn (Eds.), *Northern Powder River Basin: Wyoming and Montana* (pp. 71–86). Wyoming Geological Association and Billings Geological Society.

Craig, L.C. (1972). Mississippian System. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 100–110). Denver, Colorado: Rocky Mountain Association of Geologists.

Cygan, N.E., & Koucky, F.L. (1963). The Cambrian and Ordovician rocks of the east flank of the Big Horn Mountains, Wyoming. In G.C. Cooper, D.F. Cardinal, H.W. Lorenz & J.R. Lynn (Eds.), *Northern Powder River Basin* (pp. 26–37). Wyoming Geological Association, Billings Geological Society.

Dean, W.E., & Fouch, T.D. (1983). Lacustrine environment. In P.A. Scholle, D.G. Bebout, & C.H. Moore (Eds.), *Carbonate depositional environments* (pp. 97–130). Tulsa, Oklahoma: American Association of Petroleum Geologists.

Demko, T.M., Currie, B.S., & Nicoll, K.A. (2004). Regional paleoclimatic and stratigraphic implications of paleosols and fluvial/overbank architecture in the Morrison Formation (Upper Jurassic), Western Interior, USA. *Sedimentary Geology, 167*, 115–135.

Dickinson, W.R., Klute, M.A., Hayes, M.J., Janecke, S.U., McKittrick, M.A., & Olivares, M.D. (1988). Paleogeographic and paleotectonic setting of Laramide sedimentary basins in the central Rock Mountain region. *Geological Society of America Bulletin, 100*, 1023–1039.

Dionne, J.C. (1974). Mud cracks and polygons on ice push ridges, in tidal flats of the St. Lawrence Estuary. *Canadian Journal of Earth Sciences, 11*, 489–494.

Eicher, D.L. (1960). *Stratigraphy and micropaleontology of the Thermopolis Shale*. New Haven, Connecticut: Peabody Museum of Natural History, Bulletin 15.

Ezquerra, R., Doublet, S., Costeur, L., Galton, P.M., & Perez-Lorente, F. (2007). Were non-avian theropod dinosaurs able to swim? Supportive evidence from an Early Cretaceous trackway, Cameros Basin (La Rioja, Spain). *Geology, 35*(6), 507–510.

Fisher, J.H. (1963). Tensleep Sandstone of the eastern Big Horn Mountains, Wyoming. In G.C. Cooper, D.F. Cardinal, H.W. Lorenz & J.R. Lynn (Eds.), *Northern Powder River Basin* (pp. 54–60). Wyoming Geological Association, Billings Geological Society.

Foster, N.H. (1972). Ordovician System. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 76–85). Denver, Colorado: Rocky Mountain Association of Geologists.

Freeman, W.E., & Visher, G.S. (1975). Stratigraphic analysis of the Navajo Sandstone. *Journal of Sedimentary Petrology, 45*(3), 651–668.

Garner, P. (1996a). Continental flood basalts indicate a pre-Mesozoic Flood/post-Flood boundary. *Creation Ex Nihilo Technical Journal, 10*(1), 114–127.

Garner, P. (1996b). Where is the Flood/post-Flood boundary? Implications of dinosaur nests in the Mesozoic. *Creation Ex Nihilo Technical Journal, 10*(1), 101–106.

Gorman, D.R. (1963). Stratigraphic-sedimentological aspects of the Amsden Formation: Big Horn Mountains, Wyoming. In G.C. Cooper, D.F. Cardinal, H.W. Lorenz & J.R. Lynn (Eds.), *Northern Powder River Basin* (pp. 67–70). Wyoming Geological Association, Billings Geological Society.

Grande, L. (1984). *Paleontology of the Green River Formation, with a review of the fish fauna* (2nd ed.). Laramie, Wyoming: The Geological Survey of Wyoming, Bulletin 63.

Grande, L. (2001). An updated review of the fish faunas from the Green River Formation, the world's most productive freshwater lagerstätten. In G.F. Gunnell (Ed.), *Eocene biodiversity* (pp. 1–38). New York: Kluwer Academic/Plenum Publishers.

Hardie, L.A., Smoot, J.P., & Eugster, H.P. (1978). Saline lakes and their deposits: a sedimentological approach. In A. Matter & M.E. Tucker (Eds.), *Modern and ancient lake sediments* (pp. 7–41). Oxford: Blackwell Scientific Publications.

Harr, N.J. (1972). Phosphatic rocks. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 322–323). Denver, Colorado: Rocky Mountain Association of Geologists.

Harris, J.D., & Lacovara, K.J. (2004). Enigmatic fossil footprints from the Sundance Formation (Upper Jurassic) of Bighorn Canyon National Recreation Area, Wyoming. *Ichnos, 11*, 151–166.

Hasiotis, S.T. (2004). Reconnaissance of Upper Jurassic Morrison Formation ichnofossils, Rocky Mountain region, USA: Paleoenvironmental, stratigraphic, and paleoclimatic significance of terrestrial and freshwater ichnocoenoses. *Sedimentary Geology, 167*, 177–268.

Helman, R.P. (1957). *The petrology of the Cloverly Formation.* Unpublished masters thesis, Miami University, Oxford, Ohio.

Hoesch, W., & Austin, S.A. (2004). Dinosaur National Monument: Jurassic Park or Jurassic Jumble? *Institute for Creation Research Impact #370*, i–viii.

Holt, R.D. (1996). Evidence for a Late Cainozoic Flood/post-Flood boundary. *Creation Ex Nihilo Technical Journal, 10*(1), 128–167.

Hovland, M., Rueslatten, H.G., Johnsen, H.K., Kvamme, B., & Kuznetsova, T. (2006). Salt formation associated with sub-surface boiling and supercritical water. *Marine and Petroleum Geology, 23*, 855–869.

Ishigaki, S. (1989). Footprints of swimming sauropods from Morocco. In D.D. Gillette & M.G. Lockley (Eds.), *Dinosaur tracks and traces* (pp. 83–86). Cambridge: Cambridge University Press.

Johnson, R.C. (1985). Early Cenozoic history of the Uinta and Piceance Creek Basins, Utah and Colorado, with special reference to the development of Eocene Lake Uinta. In R.M. Flores & S.S. Kaplan (Eds.), *Cenozoic paleogeography of west-central United States* (pp. 247–276). Denver, Colorado: Rocky Mountain Section—S.E.P.M.

Johnson, R.C., & May, F. (1980). A study of the Cretaceous-Tertiary unconformity in the Piceance Creek Basin, Colorado: the underlying Ohio Creek Formation (Upper Cretaceous) redefined as a member of the Hunter Canyon or Mesaverde Formation. *U.S. Geological Survey Bulletin, 1482 B*, 1–27.

Kent, H.C. (1972). Review of Phanerozoic history. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 57–59). Denver, Colorado: Rocky Mountain Association of Geologists.

Koucky, F.L., & Rhodes, F.H.T. (1963). The Devonian rock of the east flank of the Big Horn Mountains, Wyoming. In G.C. Cooper, D.F. Cardinal, H.W. Lorenz & J.R. Lynn (Eds.), *Northern Powder River Basin* (pp. 38–44). Wyoming Geological Association, Billings Geological Society.

Leggitt, V.L., & Cushman, R.A. (2001). Complex caddisfly-dominated bioherms from the Eocene Green River Formation. *Sedimentary Geology, 145*(3–4), 377–396.

Lochman-Balk, C. (1972). Cambrian system. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 60–75). Denver, Colorado: Rocky Mountain Association of Geologists.

Lockley, M.G., & Hunt, A.P. (1995). *Dinosaur tracks and other fossil footprints of the western United States.* New York: Columbia University Press.

MacLachlan, M.E. (1972). Triassic System. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 166–176). Denver, Colorado: Rocky Mountain Association of Geologists.

Mallory, W.W. (1972). Regional synthesis of the Pennsylvanian System. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 111–127). Denver, Colorado: Rocky Mountain Association of Geologists.

Martini, I.P., Baker, V.R., & Garzon, G. (Eds.). (2002). *Flood and megaflood processes and deposits: Recent and ancient examples.* Oxford: Blackwell Science.

McGookey, D.P. (1972). Cretaceous system. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 190–228). Denver, Colorado: Rocky Mountain Association of Geologists.

McKee, E.D. (1979). Ancient sandstones considered to be eolian. In E.D. McKee (Ed.), *A study of global sand seas, USGS Professional Paper 1052* (pp. 187–238).

Middleton, L.T., Steidtmann, J.R., & DeBour, D.A. (1980). Stratigraphy and depositional setting of some Middle and Upper Cambrian rocks, Wyoming. In A. Harrison (Ed.), *Stratigraphy of Wyoming* (pp. 23–35). Jackson Hole, Wyoming: Wyoming Geological Association, 31st Annual Field Conference.

Oard, M.J. (1990). *An ice age caused by the Genesis Flood.* El Cajon, California: Institute for Creation Research.

Oard, M.J. (1996). Where is the Flood/post-Flood boundary in the rock record? *TJ, 10*(2), 258–278.

Oard, M.J. (1997). *Ancient ice ages or gigantic submarine landslides?* St. Joseph, Missouri: Creation Research Society Books.

Oard, M.J. (2004). *The Missoula Flood controversy and the Genesis Flood.* Chino Valley, Arizona: Creation Research Society.

Oard, M.J. (2006). The case for the Flood deposition of the Green River Formation. *Journal of Creation, 20*(1), 50–54.

Ollier, C., & Pain, C. (2000). *The origin of mountains.* London: Routledge.

Ostrom, J.H. (1970). *Stratigraphy and paleontology of the Cloverly Formation (Lower Cretaceous) of the Bighorn Basin area, Wyoming and Montana.* New Haven, Connecticut: Peabody Museum of Natural History, Bulletin 35.

Petersen, F.S. (1987). *Lacustrine deltaic deposits of the Sandstone Tongue of the Wasatch Formation, Fossil Basin, Wyoming.* Unpublished Masters Thesis, Loma Linda University, Loma Linda, California.

Peterson, J.A. (1972). Jurassic system. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 177–189). Denver, Colorado: Rocky Mountain Association of Geologists.

Picard, M.D., & High, L.R., Jr. (1972). Criteria for recognizing lacustrine rocks. In J.K. Rigby & W.K. Hamblin (Eds.), *Recognition of ancient sedimentary environments*

(pp. 108–145). Society of Economic Paleontologists and Mineralogists, Special Publication No. 16.

Rascoe, B., Jr., & Baars, D.L. (1972). Permian System. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 143–165). Denver, Colorado: Rocky Mountain Association of Geologists.

Rautman, C.A. (1978). Sedimentology of Late Jurassic barrier-island complex—Lower Sundance Formation of Black Hills. *The American Association of Petroleum Geologists Bulletin, 62*(11), 2275–2289.

Robinson, P. (1972). Tertiary history. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 233–242). Denver, Colorado: Rocky Mountain Association of Geologists.

Robinson, S.J. (1996). Can Flood geology explain the fossil record? *Creation Ex Nihilo Technical Journal, 10*(1), 32–69.

Robinson, S.J. (2000). The then world with water having been deluged perished. *Origins* (Biblical Creation Society), *29*, 15–24.

Roehler, H.W. (1990). Stratigraphy of the Mesaverde Group in the central and eastern Greater Green River Basin, Wyoming, Colorado, and Utah. *U.S. Geological Survey Professional Paper, 1508*, 1–52.

Roehler, H.W. (1992a). Correlation, composition, aerial distribution, and thickness of Eocene stratigraphic units, Greater Green River Basin, Wyoming, Utah, Colorado. *U.S. Geological Society Professional Paper, 1506-E*, 1–49.

Roehler, H.W. (1992b). Introduction to greater Green River Basin geology, physiography, and history of investigations. *U.S. Geological Survey Professional Paper 1506-A,* 1–14.

Roehler, H.W. (1993a). Coastal sedimentation along a segment of the interior seaway of North America, Upper Cretaceous Baxter Shale, and Blair and Rock Springs Formations, Rock Springs Uplift, Southwest Wyoming. *U.S. Geological Survey Bulletin, 2051*, 1–31.

Roehler, H.W. (1993b). Eocene climates, depositional environments, and geography, Greater Green River basin, Wyoming, Utah, and Colorado. *U.S. Geological Society Professional Paper, 1506-F*, 1–74.

Roehler, H.W. (1993c). Stratigraphy of the Upper Cretaceous Fox Hills Sandstone and adjacent parts of the Lewis Shale and Lance Formation, east flank of the Rock Springs Uplift, Southwest Wyoming. *U.S. Geological Society Professional Paper, 1532*, 1–57.

Roehler, H.W., & Stanton, R.W. (1992). Geological investigations of the Wamsutter Rim canneloid coal bed in the Eocene Niland Tongue of the Wasatch Formation, northern Washakie Basin, southwest Wyoming. *U.S. Geological Survey Bulletin, 2018*, 1–16.

Rubey, W.W., Oriel, S.S., & Tracey, J.I., Jr. (1975). Geology of the Sage and Kemmerer 15-minute quadrangles, Lincoln County, Wyoming. *U.S. Geological Society Professional Paper, 855*, 1–17.

Sando, W.J., Mackenzie, G., Jr., & Dutro, J.T., Jr. (1975). Stratigraphy and geologic history of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming. *U.S. Geological Survey Professional Paper, 848-A*, 1–48.

Seeland, D. (1992). Depositional systems of a synorogenic continental deposit—The Upper Paleocene and Lower Eocene Wasatch Formation of the Powder River Basin, northeast Wyoming. *U.S. Geological Survey Bulletin, 1917 H*, 1–20.

Sloss, L.L. (1988). Forty years of sequence stratigraphy. *Geological Society of America Bulletin, 100*(11), 1661–1665.

Sutherland, P.K. (1972). Pennsylvanian stratigraphy, southern Sangre de Cristo Mountains, New Mexico. In W.W. Mallory (Ed.), *Geologic atlas of the Rocky Mountain region* (pp. 139–142). Denver, Colorado: Rocky Mountain Association of Geologists.

Turner, C.E., & Peterson, F. (1998). *The Morrison Formation extinct ecosystems project—final report.* National Park Service/United States Geological Survey Interagency Agreement No. 1443-IA-1200-94-003.

Turner, C.E., & Peterson, F. (2004). Reconstruction of the Upper Jurassic Morrison Formation extinct ecosystem—a synthesis. *Sedimentary Geology, 167*, 309–355.

Tyler, D.J. (2006). Recolonization and the Mabbul. In J.K. Reed & M.J. Oard (Eds.), *The geologic column: perspectives within Diluvial geology* (pp. 73–86). Chino Valley, Arizona: Creation Research Society.

Uhlir, D.M., Akers, A., & Vondra, C.F. (1988). Tidal inlet sequence, Sundance Formation (Upper Jurassic), north-central Wyoming. *Sedimentology, 35*, 739–752.

Vardiman, L. (2003). Hypercanes following the Genesis Flood. In R.L. Ivey, Jr. (Ed.), *Proceedings of the fifth international conference on creationism* (pp. 17–28). Pittsburgh, Pennsylvania: Creation Science Fellowship.

Visher, G.S. (1990). *Exploration stratigraphy* (2nd ed.). Tulsa, Oklahoma: Penn Well Books.

Walker, T. (2003). Paleosols: Digging deeper buries 'challenge' to Flood geology. *TJ, 17*(3), 28–34.

Wanless, H.R., Belknap, R.L., & Foster, H. (1955). *Paleozoic and Mesozoic Rocks of Gros Ventre, Teton, Hoback and Snake River Ranges, Wyoming.* New York: Geological Society of America, Memoir 63.

Watson, J.E. (1980). *Catalog of Wyoming stratigraphy.* Casper, Wyoming: Tooke Engineering.

Whitcomb, J.C., & Morris, H.M. (1961). *The Genesis Flood: The biblical record and its scientific implications.* Phillipsburg, New Jersey: Presbyterian and Reformed.

Whitmore, J.H. (2003). *Experimental fish taphonomy with a comparison to fossil fishes.* Unpublished PhD thesis, Loma Linda University, Loma Linda, California.

Whitmore, J.H. (2006a). Difficulties with a Flood model for the Green River Formation. *Journal of Creation, 20*(1), 81–85.

Whitmore, J.H. (2006b). The geologic setting of the Green River Formation. *Journal of Creation, 20*(1), 72–78.

Whitmore, J.H. (2006c). The Green River Formation: A large post-Flood lake system. *Journal of Creation, 20*(1), 55–63.

Whitmore, J.H. (in press). Do "mud cracks" indicate multiple droughts during the Flood? In J.K. Reed & M.J. Oard (Eds.), *Flood geology answers its critics.* Green Forest, Arkansas: Master Books.

Whitmore, J.H., & Wise, K.P. (2008). Rapid and early post-Flood mammalian diversification evidenced in the Green River Formation. In A.A. Snelling (Ed.), *Proceedings of the sixth international conference on creationism* (pp. 449–457). Pittsburgh, Pennsylvania: Creation Science Fellowship & Dallas, Texas: Institute for Creation Research.

Wicander, R., & Monroe, J.S. (2004). *Historical geology* (4th ed.). Belmont, California: Brooks/Cole-Thompson Learning.

Wise, K.P. (1989). Punc eq creation style. *Origins* (Geoscience Research Institute)*, 16,* 11–24.

Wise, K.P. (2003a). Hydrothermal biome: A pre-Flood environment. In R.L. Ivey, Jr. (Ed.), *Proceedings of the fifth international conference on creationism* (pp. 359–370). Pittsburgh, Pennsylvania: Creation Science Fellowship.

Wise, K.P. (2003b). The pre-Flood floating forest: A study in paleontological pattern recognition. In R.L. Ivey, Jr. (Ed.), *Proceedings of the fifth international conference on creationism* (pp. 371–381). Pittsburgh, Pennsylvania: Creation Science Fellowship.

Wood, T.C. (2002). The AGEing process: Rapid post-Flood intrabaraminic diversification caused by altruistic genetic elements (AGEs). *Origins* (Geoscience Research Institute), *54,* 5–34.

Yuretich, R.F., Hickey, L.J., Gregson, B.P., & Hsia, Y.-L. (1984). Lacustrine deposits in the Paleocene Fort Union Formation, northeastern Bighorn Basin, Montana. *Journal of Sedimentary Petrology, 54*(3), 836–852.

Appendix

The Lithostratigraphic Column of Wyoming

A typical lithostratigraphic column of western Wyoming is presented as an example of how to apply our model. We have chosen to describe only the major formations, most of which have equivalents across the western United States. Local variations and additional formations occur in local sections. More detail about some formations is given if, according to conventional geology, they are non-marine (making them difficult to place within a Flood model) or if they occur at critical spots for our criteria model. Numerous references could be cited concerning many of these formations, but we have chosen to generalize where possible, as the main goal of this paper is to illustrate how to use our model. For the purpose of argument, we have chosen not to use terms like "Cambrian" and "Ordovician" in most cases because these terms have biostratigraphical and age connotations.

Exposed in many of the mountain ranges of Wyoming, Utah, and Colorado are igneous and metamorphic rocks that make up the craton of North America. These rocks are typically deeply buried, unless they are pushed up from below and exposed in the cores of mountain ranges (Figure 4). Conventional radioisotope dating puts some of these rocks as the oldest in North America (for example, the Beartooth Gneiss of NW Wyoming and Montana dates at about 3.5Ga). The relationships these rocks have with surrounding rock (dating by relative instead of absolute means) indicate these are indeed the oldest known rocks of the area.

The igneous and metamorphic craton is unconformably overlain by sedimentary rock. The unconformity is often expressed as a surface of great relief, sometimes covered with massive boulders.
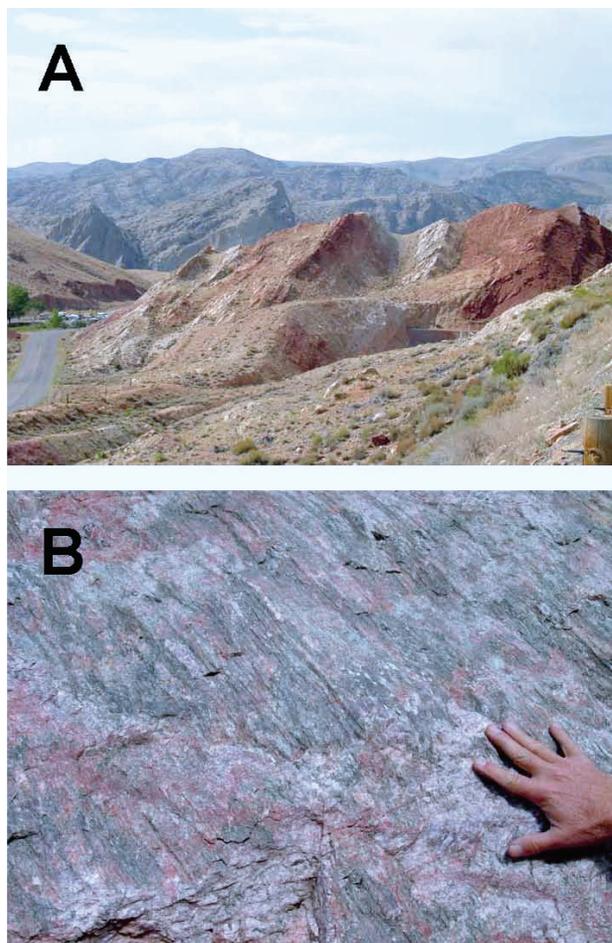

Figure 4. The Owl Creek Mountains, like other mountain ranges in Wyoming, have a crystalline core that was pushed up from deep below, tilting the marine sedimentary above them. A. The tilted marine rocks on the outskirts of the mountain range. B. Part of the crystalline core of the mountains.

Unconformities above the crystalline basement rocks are common in Wyoming (Figure 5) and in many other places around North America including the Grand
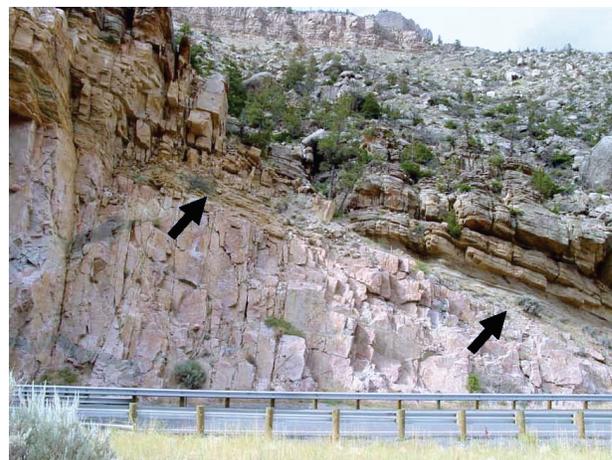

Figure 5. The Great Unconformity, near Cody, Wyoming. Granite underlies the Flathead Sandstone (indicated by arrows).

Canyon and the Black Hills of South Dakota. The marine sedimentary package above the crystalline basement was apparently transgressive and spread from west to east across the Rocky Mountain region with carbonates dominating in the west, mixed carbonates and clastics in the middle, and clastics in the east (Kent, 1972). In Wyoming these rocks are represented by a classic marine transgressive sequence comprising the Flathead Sandstone, the Gros Ventre Formation (shale), and the Gallatin Limestone. These formations are widespread throughout the Rocky Mountain Region with lithostratigraphic correlatives stretching from Canada to Mexico (Lochman-Balk, 1972). A similar transgressive sequence can be found in the eastern United States. The metazoan fossil record begins with this first package of marine rocks. In these rocks, fossils representing nearly every animal phylum make their first appearance in this region. The sudden appearance of fossils, without obvious transitions from lower forms, is sometimes referred to globally as the "Cambrian Explosion."

In Wyoming the marine section overlying the igneous and metamorphic core is thicker in the west and thinner in the east. The section begins with the Flathead Sandstone. Before erosion, the Flathead was thought to have been as much as 183 m thick in western Wyoming and it correlates with the Tintic Quartzite and the Tapeats Sandstone to the south (Lochman-Balk, 1972). It continues as the Flathead Formation into Alberta. (Middleton, Steidtmann, & DeBour, 1980) report that the Flathead consists primarily of coarse- to fine-grained sandstones and granule and small pebble conglomerates, with coarser lithologies near the base. Cross-stratification commonly occurs as trough and planar sets. Horizontal, low-angle cross-stratification is more common toward the top of the formation. In general, the unit becomes finer-grained upward, eventually grading into the Gros Ventre shales. Relief on the crystalline basement is reported to be as much as 120 m, but is commonly less than 10 m. Fossils in the formation include trace fossils (*Skolithos*), inarticulate brachiopods (*Lingulepis*) and rare trilobites. Watson (1980) reports the Flathead is a transgressive marine unit with an basal arkosic member that is so thick in spots that it almost appears to grade into the underlying granite in places. Also he mentions that sandy micaceous shale and oolitic hematite comprise some of the upper beds.

The Gros Ventre Group consists of the Wolsey Shale, the Death Canyon Limestone and the Park Shale in the area of the Teton Range of western Wyoming. To the east, the group is recognized as the Gros Ventre Formation. The Group has correlatives from Canada to Arizona and California, including the Bright Angel Shale and Muav Formation of the Grand Canyon (Lochman-Balk, 1972). Middleton, Steidtmann, &

DeBour, (1980) report that the Flathead gradually grades into the Wolsey. The Wolsey consists of a micaceous sandy shale with fine-grained glauconitic sandstone and thin interbeds of limestone. Sandstones are more abundant near the contact with the Flathead, and exhibit small-scale cross-stratification. In the northern part of the Wind River Range, the shale averages about 30 m thick. Trace fossils include *Planolites*, *Cruziana*, *Rusophycus*, *Skolithos*, and *Monocraterion*. Middleton, Steidtmann, & DeBour, (1980) report that the Death Canyon Limestone has a maximum thickness of 105 m in northwestern Wyoming and thins to the east. It contains trilobites including *Bathyriscus* and *Elrathina*. Middleton, Steidtmann, & DeBour, (1980) report that the Park Shale is micaceous and interbedded with limestone which becomes more abundant toward the top. The unit locally contains abundant sand and glauconite. The average thickness is about 120 m in western Wyoming. Toward the top of the unit intraformational conglomerates, trilobite fragments, oolites and algal structures are common. Some of the algal domes are large (~1 m high). Watson (1980) reports that the underlying Flathead grades into the marine Gros Ventre and it often consists of red, glauconitic sandstone, green and red shales, scattered massive gray-mottled limestones, thinly bedded limestones and flat pebble limestone conglomerates.

The Gallatin Limestone (consisting of several formations) overlies the Gros Ventre. It consists of carbonates and fine-grained clastics. The unit is extensive, with correlatives from Canada to Arizona, including the Muav Formation of the Grand Canyon region (Lochman-Balk, 1972). Middleton, Steidtmann, & DeBour, (1980) report that the contact between the Gallatin and Gros Ventre is conformable. Flat pebble conglomerates and glauconitic limestones commonly occur at its base and in other parts of the group. Small- and medium-scale cross-stratification and algal stromatolites can be found within. The thickness of the Gallatin is about 60 m in western Wyoming. Trilobite fragments can be found within including *Cedaria*, *Crepicephalus*, *Aphelaspis* and *Elvinia*. Watson (1980) reports the marine Gallatin group is conformable with the underlying Gros Ventre sediments and it primarily consists of glauconitic flat-pebble limestone conglomerates (some edgewise), thin interbedded limestones and calcareous shales.

The next package of sediments consists of marine carbonates. In Wyoming the Bighorn Dolomite and the Madison Limestone are persistent. Lithologic equivalents of the Bighorn Dolomite stretch from Nevada to Minnesota and from Saskatchewan to Nebraska (Foster, 1972). In the Big Horn Mountains, Cygan and Koucky (1963) measured 118 m of Big Horn Dolomite. They also report that the lower

part of the unit contains some quartz, clay minerals and gypsum. Fossils from the dolomite include *Halysites*, *Receptaculites*, *Hormotoma*, *Rafinesquina* and *Streptalasma*. Watson (1980) reports the lower contact is unconformable with the Gallatin and that the Bighorn is a massive, light gray dolomite. The Madison Limestone is represented by equivalents from Canada to Arizona and from Nevada to Kansas (Craig, 1972), including the Redwall Limestone of the Grand Canyon and the Pahasapa Limestone of the Black Hills. The unit averages from 150–300 m in thickness throughout the area (Craig, 1972) making it one of the most persistent and thickest units throughout the western USA. The same lithologic equivalent may in fact be present on many other continents as well (Ager, 1983), although intercontinental correlation is ultimately accomplished through biostratigraphy. Koucky and Rhodes (1963) report that most geologists believe a large unconformity exists between the Bighorn and Madison, but they found none in the fresh highway exposures along US 14 in the Big Horn Mountains. Watson (1980) reports that both the upper and lower contacts of the Madison are unconformable and that it consists of gray interbedded limestones, dolomite and gray calcareous shales with thin, bedded chert.

In Wyoming the Madison Limestone is generally followed by clastic units including the Amsden Formation and the Tensleep Sandstone. Fisher (1963) reports that the Amsden consists of a red sandstone, red sandstone-limestone breccia, red shale, and interbedded dolomites and limestones. Chert may be common in some layers. The upper contact with the Tensleep is usually marked by about 0.5 m of dark purple shales in the eastern Big Horn Mountains. Gorman (1963) reports a thickness of 76 m near US Hwy 14 with over 100 lithologic changes in the Amsden section. He also reports pisolites and brachiopods occurring in parts of the formation. The formation is sparsely fossiliferous, but contains taxa from most marine groups (Sando, Mackenzie, & Dutro, 1975). Watson (1980) reports that the marine Amsden has a lower unconformable contact with the Madison, consists of red shale, white limestone, cherty and sandy limestone, and dolomitic sandstone.

The cross-bedded Tensleep Sandstone correlates with other sandstones including the Quadrant and Casper of Wyoming, the Weber of Utah and Colorado, the Fountain Formation of Colorado and part of the Supai Group in the Grand Canyon region (Mallory, 1972). In western Wyoming it ranges between 30–275 m. The unit is made up of nearly pure, well-sorted, fine to very fine, angular to subangular quartz grains (Fisher, 1963). Fisher (1963) also reports that two thick (8 m) sandy limestones occur near the top of one section. Fossils are rare in the Tensleep, but

Fisher (1963) reports a few fusulinids in some of the calcareous zones of the formation. Rascoe and Baars (1972) report that part of the Tensleep Formation is correlative with the Minnelusa Formation (a complex of sandstones and carbonates in Wyoming, North Dakota, South Dakota, and Nebraska), the cross-bedded Weber Sandstone of Utah and Colorado, the Cedar Mesa Sandstone of southern Utah and the Esplanade Sandstone of the Grand Canyon region. The Cedar Mesa and the Esplanade grade into the widespread Cutler and Abo Formations of the Four Corners area. Watson (1980) reports that the Tensleep is marine and that the lower contact with the Amsden is unconformable and that small beds of dolomite, sandy-dolomite and limestone are occasionally found within.

The Phosphoria Formation contains fusulinid, cephalopod, and brachiopod faunas (Sutherland, 1972). It is one of the largest reserves of phosphate in the world and outcrops in Idaho, Montana, Utah, and Wyoming (Harr, 1972). In Wyoming, the Phosphoria grades laterally into the Park City and Chugwater Formations. The Phosphoria and the Park City have many widespread correlatives in the Rocky Mountain region and to the east, including the Goose Egg Group and part of the Spearfish Formation (Rascoe & Baars, 1972). These formations extend from North Dakota to Texas. The Phosphoria extends to central and southern Utah where it becomes a limestone known as the "Kaibab Formation." This formation contains a marine fauna, but may not be quite equivalent to the Kaibab Formation known from the Grand Canyon (Rascoe & Baars, 1972). Lithologies in the Phosphoria and Park City include limestone, sandy limestone, mudstone, siltstone, gypsum, and halite. Watson (1980) reports that the lower contact of the Phosphoria is unconformable with the Tensleep and that the Phosphoria consists of a wide variety of lithologies including phosphorite, carbonaceous mudstones, chert, and sandstones which are all characterized by intertonguing and rapid facies changes.

According to Wanless, Belknap, & Foster (1955), the Dinwoody Formation consists of light-brown or tan siltstones, fine sandstone and shale interbedded with thin bedded limestones; it is in excess of 160 m in the Snake River Range; it contains marine fossils (*Lingula*); and it rests unconformably on the Phosphoria Formation, sometimes containing a basal conglomerate with clasts of Phosphoria lithology. Watson (1980) reports the marine Dinwoody is both unconformable and conformable with the Phosphoria and that it consists of buff, tan and olive silty limestones, calcareous siltstones, olive to gray shale, olive and gray anhydrite and pyrite as a common accessory in the shales and siltstones. The Dinwoody

Figure 6. Large cross bed sets are common in the Navajo Sandstone, an equivalent of the Nugget Sandstone in Wyoming. Here, in Zion National Park, Utah, the cross bed sets are about 10 m thick.

has equivalents that extend from Arizona to Canada including parts of the Moenkopi and Spearfish Formations (MacLachlan, 1972).

The Chugwater Group consists of a variety of red lithologies including silty marine mudstones and shales. In the Powder River Basin, the group is about 300 m thick (Cavaroc & Flores, 1991). A number of environmental interpretations have been made for the formations in this complex group and its equivalents including fluvial, lacustrine, deltaic, tidal flat, near-shore marine shelf, tidal flat and coastal; all of which interfinger with a thick marine sequence in western Wyoming (Cavaroc & Flores, 1991). Part of the Spearfish Formation of Wyoming and South Dakota and the Moenkopi of Arizona and Utah are correlatives (MacLachlan, 1972). Watson (1980) reports that the lower contact is conformable with the Dinwoody and that the Chugwater consists of red and gray siltstones and shales, silty sandstones, thin bedded limestones

Figure 7. Occasionally large contorted cross beds can be found in the Navajo Sandstone. Soft sediment deformation can occur in a number of ways including dewatering and liquefaction. The conventional view is the contortion represents slumped dune faces. The deformed cross bed set is about 4 m thick. Photo near Kanab, Utah.

and limestone pebble conglomerates that formed in shallow marine environments.

The cross-bedded Nugget Sandstone is equivalent to the Navajo and Aztec Sandstones which outcrop in California, Nevada, Utah, Arizona, Colorado, Wyoming and Idaho (Peterson, 1972). According to McKee (1979) the sandstone body extends 965 km from north to south and at least 400 km from east to west; it is more than 300 m thick in parts of northeastern Arizona, more than 600 m thick in southwestern Utah and more than 900 m thick in the Mohave Desert of California. It is a wedge-shaped body which gets thicker to the west. Along the southern margin of the body, large tongues of cross-bedded sandstone interfinger with the Kayenta Formation. McKee (1979) reports that the sandstone is nearly everywhere a fine-grained, rounded to sub-rounded quartz sand, homogeneous and well-sorted. Frosting occurs on many of the grains. Large tabular type cross-bed sets are common (Figure 6). Occasionally large contorted beds can be found within the formation (Figure 7). Most conventional geologists believe the massive sand deposit is aeolian (primarily because of the large sweeping cross-beds), but some believe it may represent marine shelf deposits or a subaqueous sand wave facies (Freeman & Visher, 1975; Visher, 1990). Part of the evidence is based on the study of log-probability plots of the Navajo sand grains and their favorable comparison with similar plots from subaqueous environments. Watson (1980) reports that the Nugget was deposited in a non-marine, but near-shore aeolian or shore beach environment.

The Sundance Formation is largely a marine formation, most of which accumulated in the "Sundance Sea" (Wicander & Monroe, 2004) although it contains tracks originating from terrestrial organisms (Harris & Lacovara, 2004), probably walking on tidal flats. Correlative marine deposits stretch from southern New Mexico to the Arctic (Wicander & Monroe, 2004) including the Swift and Curtis Formations. Marine fossils from the formation include a whole host of invertebrates, plesiosaurs and ichthyosaurs. The upper part of the formation contains sandstones and coquinas interpreted as shallow marine or intertidal (Uhlir, Akers, & Vondra, 1988). According to these authors, the upper part contains a coquina facies consisting of broken shell fragments (coarse sand size), medium-grained quartz sand, and black and tan chert clasts (granule and pebble sized). The coquina facies contains sets of trough cross-stratification (0.2–0.8 m sets) and larger-scale low-angle cross-stratification (0.4–1.5 m sets). Uhlir, Akers, & Vondra (1988) report that the sandstone facies consists of fine-grained quartz sand, glauconite, and traces of sand-sized chert. Sedimentary structures include small-scale (5–30 mm sets), large-scale (0.2–0.8 m

sets) and trough cross-stratification. They report that mud drapes and mud clasts (1–3 mm) are common within cross-laminated sets. Barrier island complexes have been described from the formation (Rautman, 1978). Watson (1980) reports that the Sundance was deposited in a marine setting and that its lower contact is unconformable. He describes the lower Sundance as consisting of sandstones, calcareous oolitic sandstones and shales. The upper Sundance is described as red to green shale grading upward into fine grained calcareous glauconitic sandstones.

The Morrison Formation is stratigraphically complex and extensive. It is famous worldwide for its many dinosaur bone beds including the deposits found at Dinosaur National Monument along the Utah-Colorado border. Like the other formations discussed previously, it is very thin (averaging about 75 m) compared with its widespread, lateral coverage over much of the Rocky Mountain region. It outcrops from central New Mexico to Montana and even extends, though with different names, into Alberta and British Columbia (Turner & Peterson, 2004). The Morrison sediments consist of multicolored shales, claystones and siltstones with locally interbedded lenses of cross-bedded sandstones. The sandstones are predominantly fine-grained, quartz-rich and contain a heavy mineral assemblage of abundant garnet and well-rounded zircons and tourmalines (Chisholm, 1963). There are also occasional conglomerates, thin carbonaceous beds, and lenticular carbonates. In the Colorado Plateau region, the Morrison has been formally divided into ten members. Further north and east it is largely undifferentiated, although two other formal members are recognized in Wyoming and South Dakota (Turner & Peterson, 2004). In Wyoming, the lowest unit is the Windy Hill Member, which is probably the equivalent of the upper part of the Swift Formation in Montana. The Windy Hill Member is interpreted as having been deposited in a marginal marine setting and becomes progressively younger to the north (Turner & Peterson, 2004). The Tidwell Member, which is gypsiferous in southeastern Utah (Turner & Peterson, 1998), is also regarded as partly marine in origin. However, the other members are conventionally interpreted as representing a variety of terrestrial and freshwater environments. The Salt Wash Member, for example, consists of variegated claystones, mudstones, and siltstones, with discontinuous lenses of sandstone and conglomerate. The depositional environment is conventionally reconstructed as fluvial. Another example is the Brushy Basin Member, which is finer-grained than the Salt Wash Member, and dominated by multicolored claystones, mudstones and siltstones, with only minor amounts of sandstone and conglomerate. The Brushy Basin sediments also contain large quantities of the

clay mineral smectite, which dries out to produce a distinctive, friable "popcorn" surface. The Brushy Basin deposits are conventionally thought to have formed in fluvial, deltaic and lacustrine environments. The fossils preserved in much of the Morrison also seem to represent terrestrial-freshwater ecosystems and include many species of dinosaurs, as well as crocodiles, turtles, bivalves, charophytes, ostracods and silicified wood. In addition, at least thirty fossil footprint sites, mostly representing dinosaurs but also pterosaurs and other reptiles, are known from the Morrison Formation (Lockley & Hunt, 1995). Most record just a few footprints but two Morrison localities qualify as large track sites. The first is Rancho Del Rio near State Bridge, central Colorado, where theropod and sauropod tracks occur on several different horizons. The second is along the Purgatoire River in southeastern Colorado which records over 1,300 individual tracks, mostly sauropods and theropods, on a single horizon. There are also tracks on three other levels. Paleosols are claimed at various horizons within the Morrison (Demko, Currie, & Nicoll, 2004), as well as apparently in situ termite nests in the Salt Wash Member (Hasiotis, 2004). Conventionally, then, most of the Morrison—with the exception of its lowermost part – is interpreted as having formed in continental (fluvial, alluvial, lacustrine) environments. However, based on studies of the Brushy Basin Member exposed at Dinosaur Quarry in Utah, Hoesch and Austin (2004) presented six arguments which they felt demonstrated the need to rethink the conventional environmental reconstruction. Their arguments are summarized briefly here. First, they point out that the most common fossils in the Quarry sandstone are articulated *Unio* clams that are not in their natural growth position and are believed to represent a transported death assemblage. Second, they note the many evidences of very large-scale explosive volcanism associated with the Brushy Basin Member, including bentonite beds, reworked and altered volcanic ash, and tuff pebbles—all from a distant source in southern California or Nevada. Third, they draw attention to the fact that the dinosaur remains and associated fossils have clearly been transported by water and do not represent an in situ ecological assemblage. Fourth, they propose that the agent of transport was a catastrophic, muddy suspension flow, rather than the normal bedload of an ancient river. Fifth, they argue that evidence for in situ vegetation growth—which would have been necessary to support the large sauropods found in the Morrison—is virtually non-existent. Sixth, and finally, they note that the bone-bearing horizons within the Brushy Basin Member have surprisingly high bone concentrations and seem to represent mass accumulations. We suspect that these observations,

though based largely upon a limited exposure of one Morrison member at one locality, will turn out to be more widely applicable throughout the formation.

The Cloverly Formation is interpreted to be fluvial in the Rawlin's Uplift area where it consists of a basal conglomerate, a thin limestone and sandstones (Helman, 1957). Ostrom (1970) believes that the Cloverly is non-marine; that the paleontology of the formation is distinct from that of the Morrison with very few taxon being represented in both; the stratigraphy has had a long history of change and many times the units are difficult to distinguish from the underlying Morrison; it consists mostly of variegated claystones, shales, fine-grained sandstones, and conglomeritic sandstones; some of the units contain bentonite and volcanic tuffs; some units contain coarse-grained, discontinuous channel deposits with subangular to angular sand grains; and others contain well-rounded quartz and feldspar grains. Watson (1980) reports the Clovery formed in floodplain, paludal and lacustrine environments and that its lower contact is probably conformable with the Morrison Formation.

Eicher (1960) reports that the Thermopolis Shale consists of gray and black marine shales and siltstones with a total maximum thickness of nearly 200 m; that macrofossils are uncommon, but include fossil leaves, pelecypods, gastropods, various bone fragments; and microfossils include marine foraminifera. Watson (1980) reports that the lower contact with the Cloverly Formation is probably conformable and that the Thermopolis shale is a black, fissile, marine shale containing thin sandy zones. The Thermopolis Shale and its equivalents stretch from Texas to Canada (McGookey, 1972).

Wanless, Belknap, & Foster (1955) report that the Mowry Shale consists mostly of light-gray shales with thinly bedded sandstones; it occasionally contains many fish scales, bones, and teeth; and bentonite beds are common in some places. Watson (1980) reports that the Mowry is marine and typically is dark gray to black, siliceous and bentonitic. Equivalents of the Mowry stretch from southern Colorado to Canada (McGookey, 1972).

According to Wanless, Belknap, & Foster (1955), the Frontier Formation is a coal-bearing shale and sandstone unit that is about 600 m thick; conglomerates are common in the basal part of the formation; well preserved leaves are common in some parts; and marine fossils occur in some of sections. Watson (1980) reports that the Frontier is conformable with the underlying Mowry and that the Frontier was formed in a fluvial, deltaic and marine environments consisting of sandstones, dark shales and coals. Equivalents of the Frontier Formation extend from southern Colorado to Canada and include the Mancos and Tropic Shales (McGookey, 1972).

The Baxter Shale consists of marine delta, shelf and slope deposits in excess of 1300 m thick in the area of Rock Springs, Wyoming (Roehler, 1993a). It correlates with similar formations from Mexico to Canada including part of the Mowry Shale, Eagle Ford Shale and the Tununk Shale (McGookey, 1972). Watson (1980) reports that the lower contact of the Baxter with the Frontier is conformable (interfingers) with the Frontier and it consists of silty and gypsiferous shales with thin beds of sandstone and limestone.

The Mesaverde Group is a series of mostly marine formations that outcrops and occurs in the subsurface of Wyoming. The following details about the group are summarized from Roehler (1990): it is in excess of 1,500 m thick in southwestern Wyoming; the lower part of the group was deposited during a major regression; the upper part of the group was deposited during a major transgression; the group is interpreted to represent various paleoenvironments including alluvial-plain, flood-plain, coastal-plain, barrier-plain, tidal-flat, delta-plain, marine shoreline, and marine shelf; it contains 11 ammonite zones and coal deposits and carbonaceous shales. The lower part of the unit contains some bioturbated beds and some possible vertebrate footprints (Roehler, 1993a). Watson (1980) reports that the Mesaverde was a transgressive-regressive marine sequence and that its lower contact with the Baxter is gradational. He reports that the Mesaverde consists of sandstones, shales and coal beds. At the same time the Mesaverde was being deposited, the Adaville coals were being deposited in southwestern Wyoming (McGookey, 1972). The Adaville Formation outcrops as steeply dipping units on the eastern edge of Fossil Basin and is producing commercial coal near Kemmerer, Wyoming. Correlatives of the Mesaverde extend from Canada to Texas and include the Judith River Formation (McGookey, 1972). Above the Mesaverde, on the floor of the Piceance Creek Basin of Colorado, a major unconformity exists (Johnson & May, 1980). Below the unconformity the clay-rich beds and sandstones of the Mesaverde contain chert pebbles, thin coal beds, and possible paleosols. The Adaville units are the last to be deposited before thrust faulting and uplift occurred to make Fossil Basin.

The Lance Formation follows the Mesaverde Group. In western Wyoming it has been interpreted as continental bay or lagoon deposits that were part of a regressing sea (Roehler, 1993c). Roehler reports that the formation reaches a maximum thickness of about 300 m near the Rock Springs Uplift; the formation thickens to the east; it has abundant freshwater and brackish-water mollusks and invertebrate trace fossils; it also contains wood fragments, palm leaves and occasional dinosaur bone fragments, local dinosaur tracks and coal deposits. Further to the east, in Wyoming, graded

disarticulated dinosaur bone fragments occur in large numbers. Based on the available evidence, Chadwick, Spencer, & Turner (2006) have suggested that the bones of between 10,000 and 25,000 individuals were catastrophically buried in an area of 40 hectares. The Lance Formation and its correlatives (including the Hell Creek Formation) extend from Canada to Texas (McGookey, 1972). Watson (1980) reports that the Lance is a non-marine continental deposit that formed after a marine regression which consists of carbonaceous shale, sandstone and siltstone with occasional coal beds.

Relatively small sedimentary basins occur above the thick, widespread marine deposits discussed above. These include Fossil Basin, the Greater Green River Basin, Powder River Basin, Big Horn Basin and multiple other basins occurring in the west-central United States. In Wyoming, formations filling these basins include the Wasatch and Green River Formations (GRF). Basins which contain the Wasatch and GRF are similar in structure and sediment-fill to the other sedimentary basins, and will be used as an example.

In the Powder River Basin, the lowest member of the Fort Union Formation is the Tullock Member. Brown (1993) gives the following details about the member: the sediments range in thickness from 113–439 m; together, the Fort Union and Wasatch Formations attain a maximum thickness of 2,000 m; the clastic sediments are fluvial in origin and contain fine-grained sandstone, sandy siltstone, shale, rare thin limestones, and coal; there are multiple evidences for the rapid accumulation of sediments including cross-bedded and climbing-ripple laminated sandstones, ball and pillow structures and soft-sediment deformation; there are possible paleosols in some of the beds; some beds contain carbonate clasts from underlying formations suggesting the uplift and exposure of these formations in the proto Bighorn mountains to the west; the contact of the Tullock Member with the underlying Lance and Hell Creek Formations is gradational and is sometimes difficult to identify; and fossils are not abundant but include a variety of plant flora, freshwater gastropods, and a freshwater gar. Above the Tullock Member is the Lebo Member. It is interpreted as representing lacustrine and fluvial deposits (Brown, 1993). Above the Lebo Member is the Tongue River Member which contains some of the thickest coal deposits in the United States, some in excess of 30 m (Seeland, 1992). In the Bighorn Basin, the Fort Union contains lacustrine deposits (Yuretich, Hickey, Gregson, & Hsia, 1984). Compared to the formations below it, the Fort Union and all of the formations that follow it become more localized in extent (see maps in Robinson, 1972). Watson (1980) reports that the Fort Union is probably conformable with the Lance and that the Fort Union consists of light gray to white sandstones, dark shales, a local basal conglomerate and coals.

Seeland (1992) reports that in the Powder River Basin, the Wasatch is a fluvial deposit consisting of alluvial mudstones and sandstones with a maximum thickness of 900 m. Paleocurrent directions, grain size and shape analysis and facies analysis can be used to reconstruct large drainages within the basin that are related to coal (in the Tongue River Member of the Fort Union Formation) and uranium deposits in the Wasatch sandstones. The Wasatch Formation is also interpreted to be a fluvial deposit in the Green River and Fossil Basins of southwestern Wyoming. It contains a variety of lithologies, but usually consists of red and gray sandstones and mudstones and interfingers with the lacustrine Green River Formation in the centers of these basins (Roehler, 1992b). The formation is thickest near the basin margins where it replaces the Green River Formation in vertical section. In the northeastern Greater Green River basin it is exceptionally thick (nearly 2,800 m) and grades into the fanglomerates of the Hoback and Pass Peak Formations (Roehler, 1992b). In places, the Wasatch contains coal (Roehler & Stanton, 1992).

In Fossil Basin, the Evanston, Wasatch and Green River Formations (GRF) rest directly on top of folded and eroded marine deposits (Figure 8). The first unit to be deposited on the floor of Fossil Basin was the Ham's Fork Conglomerate, a member of the Evanston Formation (Rubey, Oriel, & Tracey, 1975). The Wasatch consists of coarse fluvial deposits which interfinger with the finer-grained deposits of the GRF (Figure 9). These deposits have been discussed in more detail by Whitmore (2006a, 2006b, 2006c). The basins that are filled with GRF are isolated sedimentary basins filled with terrestrial deposits.

Figure 8. The Green River Formation is flat lying and is below the prairie grass. Marine sediments are steeply folded and form the stripped structural surface in the background. The folded marine rocks form the basin in which Fossil Basin accumulated. Compare with Figure 2.
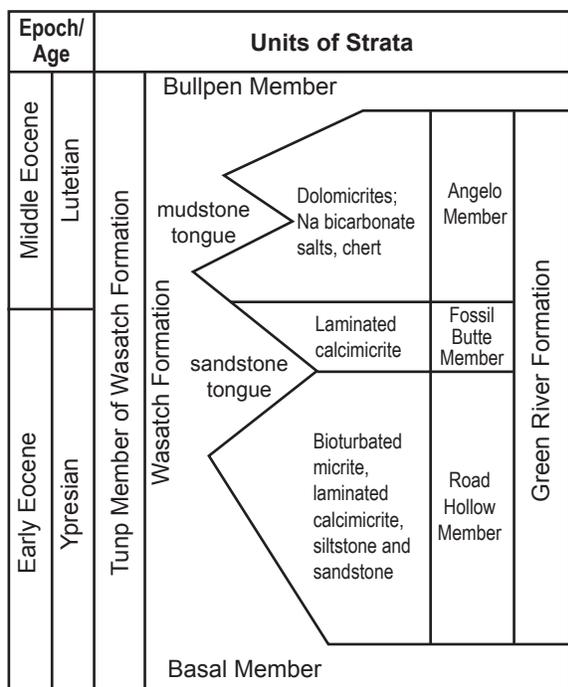
Epoch/ Age		Units of Strata			
Middle Eocene	Lutetian	Tunp Member of Wasatch Formation	Bullpen Member			Green River Formation
			mudstone tongue	Dolomicrites; Na bicarbonate salts, chert	Angelo Member	
			sandstone tongue	Laminated calcimicrite	Fossil Butte Member	
Early Eocene	Ypresian			Bioturbated micrite, laminated calcimicrite, siltstone and sandstone	Road Hollow Member	
			Basal Member			

Figure 9. The Wasatch Formation interfingers with the Green River Formation. Figure modified from Buchheim and Eugster (1998).

The GRF contains continental flora and fauna which unconformably overlie marine sediments (Dickinson, Klute, Hayes, Janecke, McKittrick, & Olivares, 1988; Roehler, 1993a). The youngest group of these underlying marine sediments formed as the interior Cretaceous Seaway regressed from the continent (Roehler, 1993c). A regional unconformity exists on the top of the thick sequence of marine rocks (Johnson, 1985). These basins, and in particular those containing the GRF, are "basins" because they were formed by various uplifts that surround them. For example, the Greater Green River Basin and Fossil Basin are surrounded by the topographic highs of

Figure 10. Tuff beds often occur in the Green River Formation as orange colored layers which are easy to identify compared to the light colored calcimicrites. Photo from Fossil Basin, Wyoming.

the Uinta Mountains (south), Wind River Mountains (north), Wasatch Range (west) and various structural highs to the east (Roehler, 1992b). All of the GRF basins contain sediments that are characteristic of lacustrine deposition. Modern lakes ideally have a "bull's-eye" pattern of concentric sediments, with coarse sediments along the edges grading to finer sediments in the middle. The GRF basins contain such patterns (Buchheim & Eugster, 1998; Picard & High, 1972). Current directions obtained from cross-beds and ripple marks show sediment transport toward the basin centers within these closed basins, exactly as predicted within a lacustrine model. For example, the deltaic facies of the Farson Sandstone (Roehler, 1992a) or the Wasatch Formation (Petersen, 1987) show such current directions. Paleontology indicates a lacustrine origin for the GRF. Bird tracks, bird nests, large stromatolites, bioturbated sediments, and large in situ caddis fly mounds (Leggitt & Cushman, 2001) only occur around basin margins, especially in the Greater Green River Basin (Roehler, 1993b). The GRF fauna is freshwater (Grande, 1984, 2001) with abundant fossils disappearing when saline sedimentary strata appear (Buchheim, 1994). Patterns of fish taphonomy (Whitmore, 2003) show the margins of Fossil Basin were shallow and the center was deeper. Whitmore demonstrated that some fish along the basin margin exploded due to decay gases erupting in shallow water. The same pattern is not seen in deeper water. The pattern demonstrates that sediments were rapidly accumulating in a lacustrine basin, but not in an overwhelming catastrophe. Fish decay patterns demonstrate the passage of time within the sediments. Whitmore demonstrated that in order for fish to be well preserved, they must be buried soon after death. This is true of the GRF fish. However, contrary to popular belief, most GRF fish are not perfect specimens. Many show various stages of decay indicating some passage of time (days) before entombment. The geochemistry of some of the rocks of the GRF seems to defy explanation via deposition of sea water. The Greater Green River Basin contains thick deposits of trona ($Na_3(CO_3)(HCO_3)·H_2O$) (Bradley & Eugster, 1969) which is chemically impossible to derive from the proportions of ions contained in seawater (Hardie, Smoot, & Eugster, 1978). Trona must come from calcium- and magnesium-poor solutions. Sea water is calcium- and magnesium-rich. Trona is currently precipitating in modern lakes, such as Lake Magadi in Kenya (Dean & Fouch, 1983).

Watson (1980) reports that the Bridger Formation is conformable with the sediments found below it. He describes the Bridger as being composed of thin freshwater tuffaceous limestones, lacustrine sandstones and shales, channel sandstone deposits, flood plain deposits, deltaic deposits (containing

sandstone and siltstone), lignite and volcanic material.

Hints of volcanic activity begin in the Morrison Formation and can be found in most of the units above. In some of the descriptions of the formations above, bentonites are reported. These are typically thought to be altered volcanic ash deposits. Altered ash beds are present in Fossil Basin (Figure 10) and pairs of ash beds can be used to identify isochronous units within the lacustrine deposits (Whitmore, 2003). Massive volcanic activity is found near the top of the section, including the very recent deposits in Yellowstone National Park.

Glacial deposits can be found in many of the Wyoming mountain ranges. Active glaciers still occur in some of the ranges including the Tetons and Wind River Mountains of western Wyoming. In the Green River Basins, glacial deposits extend outward over the Green River sediments, meaning they must have been in place prior to glaciation.