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PALEOCURRENTS AND THE GEOLOGIC RECORD

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As students of science and Scripture, we confront a certain tension between various interpretations of science and the clear teachings of Scripture about the history of life and this planet. While such tension can be healthy and can be a great stimulus for pursuing lines of research designed to clarify such issues, the same tension has been used by some as an excuse for discarding the teachings of Scripture. While it is possible that we will never have the answers to many of the scientific questions we desire in this life, I find encouragement in Scripture to continue the pursuit of resolution. It would be absurd for us to think we can by our best efforts ever expect to solve all of the questions that may arise, but we continue our work, recalling that projects we have undertaken in the past yielded alternative explanations within the context of the Scriptural paradigm of origins.

What if we could go back in time and experience some segment of the earth's history. What would we find? Would we see slow, gradual accumulation of sediments over millions of years? Would we see rapid, catastrophic processes occurring over a very short period of time? Or would we see something else? I have no doubt we would all see things differently than we imagined! While such time travel evokes striking images, it is not a tool we have at our disposal. But what if we could devise a technique to reconstruct past geologic events on a grand scale? What would we learn? What questions could we ask? What answers would we have? What other questions would arise? The possibilities are endless. While time travel remains the stuff of science fiction, there are ways we can use present knowledge to learn crucial details about the processes of the earth's past. These techniques can enable us to ask important questions about our past history that can be answered from available data.

What are Paleocurrents?

Paleocurrents are directions of movement of fluid and the entrained particles responsible for the formation of sedimentary rocks. These current directions can be retrieved from sedimentary rocks by measuring the direction and/or sense of paleocurrent indicators preserved within the rocks themselves. These paleocurrent indicators include crossbeds, ripple marks, flute and groove casts, parting lineations, fossil orientations, imbrications and other more obscure features of sedimentary rocks. Crossbeds are faint layering visible in sandstones and other clastic rocks (rocks made of particles of other rocks – sandstone, shale, etc.) that strike diagonally across the thickness of the beds. Ripple marks are miniature dunes resulting from the transport of sand and mud that are often seen on the banks of rivers and streams. Flute casts, groove casts and tool marks are structures reflecting deposition in turbidites and other mass flow phenomena that are seen most often on the underside of rock layers. Parting lineations are trains of sand grains exposed when layers of sandstone are pried apart that reflect the movement of the grains during deposition. Imbrication is the domino-like orientation of clasts resulting when the grains achieve the most stable position during deposition. All of these features are capable of yielding the kinds of data required for reconstruction of paleocurrents.

A local accumulation of paleocurrent indicators for a given sedimentary rock layer would enable us to track the directions of movement of the currents responsible for transporting the sediment and depositing it. We could tell the direction which the sediment was transported from, and by sighting up current, we could ask questions about the source of the sediment. This would be interesting, but we would have to carry our study farther upstream to search for an ultimate source for the sediment. If we had access to all of the data from all of the coeval rocks upstream, we might eventually be able to resolve the source, and we could begin to talk about the rates of movement and the processes involved in the deposition. But what if we had data for all of the layers of rock as well and could compare the movement of sediment across continents and even between one continent and another? What would we see then?

Over a period of years we have accumulated over 1 million measurements of paleocurrent data distributed throughout the geologic column from Precambrian to Recent. These data come from published geologic literature and unpublished theses and dissertations at major universities having graduate programs in geology in North and South America, in England, in Australia and in Spain. The database is limited in Africa and is very sparse in Asia, particularly China, and Russia. Each entry includes the reference source, the longitude and latitude of the location, the number of measurements, the sense of the flow, the dispersion of the measurements, the type of sediment involved, the author's designation of depositional environment, the type of paleocurrent indicator measured, the area in square kilometers from which the data were acquired, the tectonic plate number for the locality, and the formal name of the formation. A separate spreadsheet keeps track of the stratigraphic position of the formations.

We developed a software program written in C and C++ that enables flexible data display permitting analysis using a graphical interface. Because the data were acquired from thousands of sources, they do not uniformly represent the various formations and regions. For example, in one study, a hundred measurements may be derived from an area of one kilometer. In another, the author may have represented an area of 1000 km by only one measurement. Both are recorded in the database, but compensating weights are applied to minimize the tilting of outcomes. The program also permits localized averaging and display of data. The averaged data can be treated with Rayleigh statistics for circular data, can be smoothed using a running average technique, or can be displayed as rose diagrams in a variety of formats. All of these features were designed without reference to the data themselves, to prevent biasing the outcome.

The program also allows various scenarios of paleogeographic reconstructions and tectonic plate movements through time. The data are assigned to and carried on appropriate lithospheric plates. These plates can be translated (moved laterally) and/or rotated to accommodate various schemes of continental plate reconstructions. In this process, the data remain in the proper relationship to the plates in all configurations.

Plate Tectonics and a Global Flood

Our understanding of the tectonic and depositional history of the earth has undergone revolutionary changes in the past 40 years, due largely to the elaboration and broad application of the theory of plate tectonics. The changes in our thinking are so radical that the science of the earth from 40 years ago is no longer meaningful. In 1970, the crust of the earth was viewed as static. We now think of the crust of the earth as a dynamic, ever changing landscape with continents accreting and rifting only to accrete and rift again. While one can question some of the propositions, and certainly the time scale must be entirely different, the general sense is that these processes have been occurring, and to some extent are still occurring. The potential insights of plate tectonics for our understanding of earth history in the context of a global flood are enormous.

In this paper, I will begin with an introduction by example of what plate tectonics entails. Next, I will give an illustration of paleocurrent data and paleogeographic mapping for the Cambrian of North America. I will then review the basis of modern plate tectonics theory and the making of paleogeographic reconstructions. Finally, I will overlay our data from paleocurrents on state of the art paleogeographic maps for the stages of the Phanerozoic to see what we can learn about the meaning of patterns of paleocurrents and their relationship to paleogeographic, tectonic, and sedimentological reconstructions. I will conclude with an assessment of plate tectonics and paleocurrents, considering how all of this might fit into a Global Flood Model.

An Example from Plate Tectonics Theory

The geologic column is a construct of geology useful for relating the layers of rocks in the earth's crust. While geologists working within the Standard Model (i.e. millions of years, evolutionary origin of life) would generally assign time significance to the periods in the column, this is not necessary. Rock stratigraphy uses terminology that is neutral and does not attribute absolute time to the layers. For example Cambrian events in rock stratigraphical terms refers to events that occurred during the deposition of Cambrian rocks without inferences to the geologic time scale (i.e. millions of years). This paper uses rock stratigraphical terms.

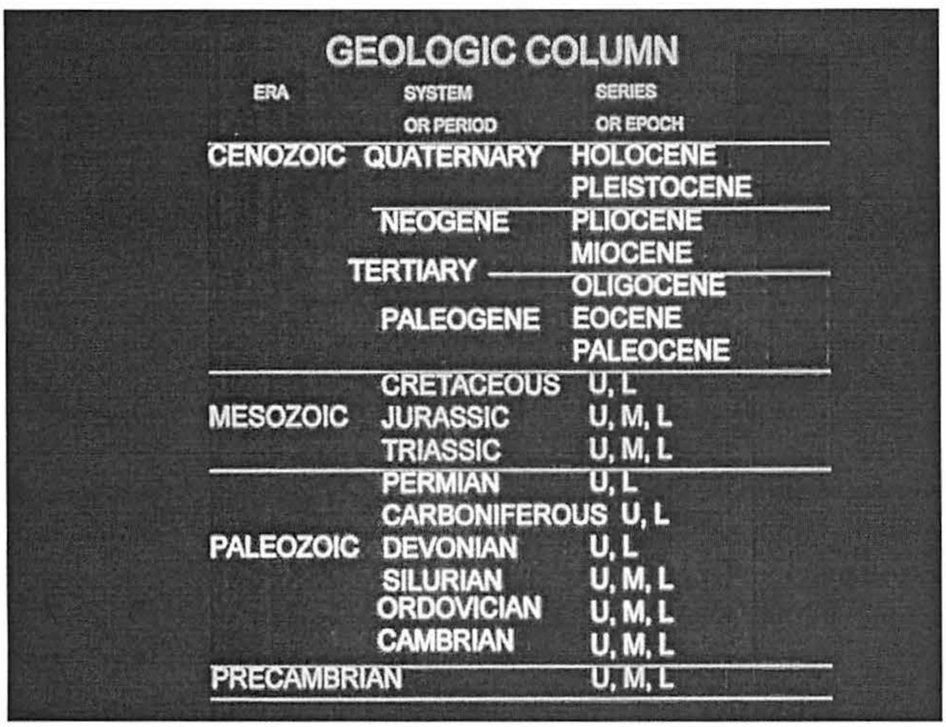

Figure 1. The Geologic Column.

At the beginning of the Paleozoic, North America is represented by a series of granitic masses thought to have been accreted in the Precambrian by collisions of mobile plates. North America is now part of a single large landmass, centered at the South Pole. This mass, dubbed Rodinia, began rifting, separating the North American granitic craton (Laurentia) from Baltica (Europe) and the remainder of Rodinia, creating a new water body in the process, the Cambrian Iapetus Ocean. During the rifting process some blocks were stranded by the rift, creating Avalonia from the east coast of Laurentia. These processes may have been associated with the major tectonic events of the beginning of the Flood of Noah, the breaking up of the fountains of the deep.

Off the east coast, subducting oceanic crust generates a volcanic arc (Taconic Arc) and brings collision in the Ordovician (Taconic Orogeny), rifting the volcanic sediments of the arc against and overriding the eastern coast of North America. Oceanic crust carrying Avalonia is drawn closer to collision with east coast in the process. In the Silurian, Avalonia collides with North America and Baltica (Europe) collides with Avalonia. Continued westward movement of these plates into the Devonian produces the Caledonian Orogeny, effecting the welding of Avalonia into portions of several continents.

This short illustration exemplifies the remarkable continental rearrangements proposed by plate tectonics theory and offers key insights as to why the world we live in is the way it is, and what kinds of processes might have transpired during the Flood.

North American Cambrian Tectonics and Paleocurrents

With this introduction to plate tectonics, let us now examine the depositional processes represented by paleocurrent patterns. We will consider the paleocurrent data from the entire Cambrian. In Figure 2, the lower left frame represents raw data with arrow sizes indicating how many points each arrow encompasses. Upper left represents average direction of the paleocurrents in each of up to 10,000 squares by a single arrow of identical size. These arrows are smoothed with a running average technique. Upper right frame is similar to upper left but the arrow sizes are relative to the number of points in that square and the data are not smoothed. Lower right gives the data as a single rose diagram, with no geographic information. This allows the observer to make judgments about the significance of the data.

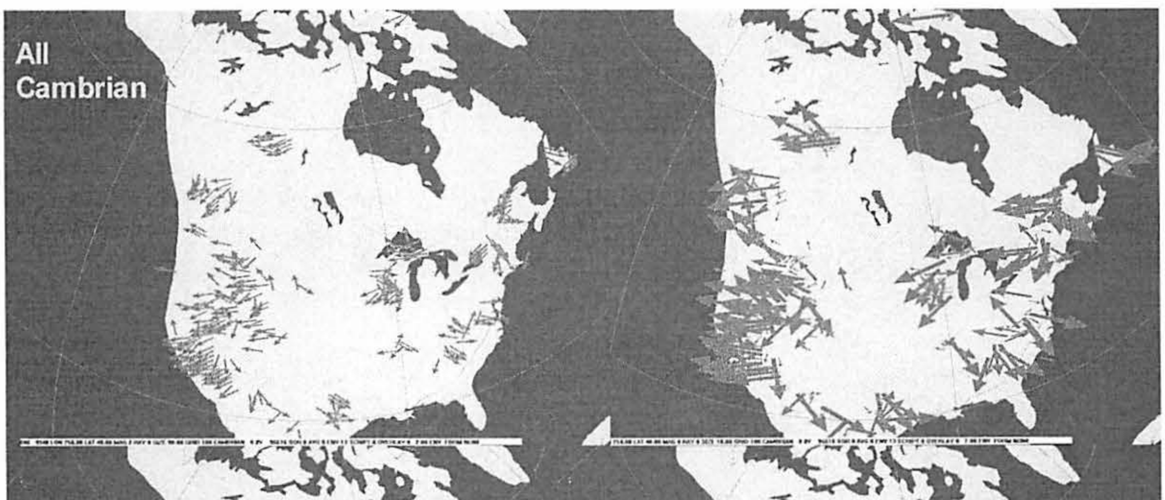

Fig. 2. Cambrian paleocurrent data displayed in various ways (see text for details)

The rose diagram demonstrates a prevalent flow towards the west and south. The story is complicated because some currents are directed eastward: along the east coast in Lower Cambrian strata, and in the south central U.S. throughout a range of Cambrian deposits. So, while a large majority of the paleocurrent data is westerly directed throughout the Cambrian sedimentary record, other data buck this trend. The data are remarkable for the magnitude of the depositional processes; the data are also unique for deposition of marine sediments on the craton, rather than in the adjacent oceans. Today no such marine depositional processes occur on any granitic continental mass. Only in the deep ocean basins can we find equivalent types of sedimentation occurring. Is this explainable within the Standard Model, or is it something that is more consistent with a global catastrophic event such as the Flood? What do the paleocurrent data indicate for other geologic layers and what can we make of the trends that we see in terms of current paleogeographic constructs?

The Bases of Paleogeographic Reconstructions

Since the mid 1960's geologists have developed the theory that the crust of the earth consists of a varying number of lithospheric plates that are floating on the semi-solid upper mantle. Convection movements within the mantle make it certain that with time these lithospheric plates are going to move, collide, subduct and regenerate on a global scale. This theory, like evolutionary theory, "is so well established that it no longer needs evidence to support it," although, unlike the theory of evolution, plate tectonics theory has substantial support including the present rates of movement of continents with respect to one another. The thinking is: "Because plates are moving now, they must have always moved and we can build paleogeographic reconstructions based on these posited motions."

Any attempts at paleogeographic reconstructions must be interpretations of various types of data found in the physical world in terms of plate tectonics theory. What kinds of data go into such maps? A few of them are:

1. Paleomagnetic data on positions of continents.
2. Sedimentary depositional data such as sediment thickness and provenance.
3. Stratigraphic and sedimentological similarities of terranes across continents.
4. Estimations of latitudes based upon paleofaunas and paleofloras and zones of evaporation.
5. Presence of exotic terranes.
6. Radiometric dates on volcanic terranes.
7. Other data.

We will briefly consider each of the above.

1. With some reasonable assumptions, paleomagnetism enables us to reconstruct the paleolatitude of a continent based upon the measured angle of the remnant incident magnetic field at the time the rocks were deposited (3). This seems to work well for relatively recent deposits, but becomes less reliable the farther back in time we go. Also, paleomagnetism gives no information on longitude, so longitude must always be based upon other inferences, even if we accept the latitude favored by paleomagnetic data.

2. Where on the craton was there water and where dry land? You will see that the artists' depictions seem quite certain about where land was and where ocean was in the diagrams. This is because the rocks deposited in each area were used to determine what environment was present for the maps. Other features are deduced from the depth of the sediments deposited. For

example, when sediments become very thick (say, 30,000 feet!) geologists reasonably assume they are at the edge of a continent. If the sediments appear to have been coming from the east, then we are at the western edge of the continent, etc. These kinds of data are used to reconstruct paleogeographic boundaries and environments.

3. Derek Ager (1), a British geologist, is best known for having pointed out the wide-spread nature of sedimentary deposits around the globe. Creationists have historically quoted Ager, suggesting the widespread distribution of sediments he described was evidence for a worldwide catastrophic flood. More recently, geologists have been using observations like those of Ager in reconstructing paleogeography. If a similar deposit is found to be present on several continents, they must have been in contact when the sediments were deposited. For example, a huge coeval lava field was found to be present in Brazil, in North America, in Europe and in India, suggesting these continents were connected when the flows developed. These kinds of data go into the building of paleogeographic reconstructions.

4. The paleolatitude of continents is determined from two types of data, paleomagnetism and paleoenvironmental reconstructions. Paleoenvironmental reconstruction involves determining the latitude of a depositional suite from the contained fossil organisms. Evaporites (salt, gypsum, etc.) are generally attributed to the subequatorial zone, so their presence is also a paleoenvironmental datum. While paleomagnetic data are useful, especially in relatively recent rocks, they are generally trumped by paleoenvironmental data when there is a conflict. Paleoenvironmental data, like paleomagnetic data, are less and less reliable the farther back we go because the organisms we are inferring environmental conditions for are less and less well known. Another vital paleoenvironmental issue that is often ignored by paleogeographers is a consideration as to whether the organisms being analyzed for environmental data were transported to the site of burial (in which case environmental constraints may not be appropriate) or whether they were buried in place. Regardless of what other issues may exist, the paleogeographic reconstructions will be less and less reliable the farther back in time we go.

5. Exotic terranes are pieces of continental crust (granitic) or pieces of oceanic crust (basaltic), often with sediments attached, that have been accreted to an existing craton during the course of plate movements. Most of California, Oregon, Washington, British Columbia and Alaska are comprised of exotic blocks of terranes scraped up off the ocean floor during the westward movement of North America. These terranes can sometimes be traced back to the source area by comparing faunal elements in the fossil suites of the attached sedimentary rocks. These data are very useful in reconstructing the history of plate motions and are among the most compelling evidences for plate tectonics theory.

6. Radiometric dates are a topic on which I will say little except that without them the time frame for plate tectonics would be difficult to reconstruct.

7. Most of the plate reconstructions (what was touching what, when) are done on the basis of matching terranes or matching tectonics on separate continents that appear to have had a common origin. Other geologic data are used that will not be considered in this paper.

The Phanerozoic in North America

The plate tectonics details I give here are contemporary. I present them as one suggestion of what **might** have taken place. Perhaps time will tell whether they become permanent additions to the plate tectonics paradigm. The paleogeographic reconstructions are presented in an attempt to illuminate events of earth history. With respect to geologic time, I take the geologic column to be a record of successive events, which I believe took place on a very short timescale of hours/days/weeks/months or years. This departure from the Standard Model is a consequence not of the geologic data themselves, but from the Biblical paradigm in which I operate. I believe this premise is defensible on scriptural grounds. It certainly is a lot more exciting way of looking at the data!

Beginning in the Upper Proterozoic, just before the Cambrian, we will move successively through the geologic column from bottom to top in the order that the layers occur. In the concept of a global flood these bottom layers would be accumulating earlier and the overlying layers later in the process. Recall that the forerunner of North America is at this time part of a single large landmass, Rodinia, centered at the South Pole which has just survived nearly total encasement in ice. During the subsequent warming period, a triple junction formed nearly mid-continent, separating North American craton (Laurentia) from Baltica (Europe) and the remainder of Rodinia, and creating a new water body in the process, the Iapetus Ocean. These processes, which would have been incredibly violent on a short time scale, may have been a part of the major tectonic events of the beginning of the Flood of Noah in the breaking up of the fountains of the deep. Up to this point there are no evidences of fossil metazoan (multicellular animal) life forms preserved in the sediments.

The presence of a single continent in Precambrian reconstructions is consistent with the wording of Genesis 1:9, and this one continent may have been the form of land on the preflood world. North America emerges from this continent just prior to the beginning of the Cambrian through a triple juncture occurring very near the then-South Pole. South of the east coast (at that time south coast) the Iapetus Ocean is actively expanding. The remnant of Rodinia is soon to be the heart of Gondwana, the new southern continent.

Turning our attention to Laurentia, the progenitor of North America, the equator is pegged somewhat west of the present west coast and parallel with that coast. The east coast has lost a substantial mass during the rifting process, giving rise to Madagascar and Avalonia, and the rifting process continues to enlarge the Iapetus Ocean. North America is at this time entirely terrestrial according to this model. Paleocurrents tell a different story, indicating deposition of marine sands with a variety of paleocurrent directions across the craton. The only places where there appears to be appropriate marine deposition is in the (modern) southwest and southeast.

Paleozoic Paleogeography

Beginning in the Lower Cambrian, a significant marine transgression deposits clastic sediments ranging from 0 to 30,000 feet thick, across the North American craton. The marine incursion changes the landscape dramatically. North America continues to move away from the South Pole, with the equator now resting somewhere in what will some day be California. The Iapetus Ocean expands to its maximum extent. A prominent Transcontinental Arch does not receive sediment and in fact could be a source for much of the Cambrian sediment. Abundant paleocurrent data reveal massive deposition in marine environments from source areas that appear to be located on the craton itself. The sediment blanket deposited in Lower Cambrian contains representatives of every major phylum of animal except one. The presence of this remarkable fossil assemblage in these sediments makes it appropriate to place the beginnings of the deposits of the Biblical Flood in Lower Cambrian.

By the time Upper Cambrian deposition has ended, the Transcontinental Arch has narrowed greatly and much of it has been covered by Cambrian sediment. The Iapetus Ocean is narrowing again and the previously rifted arcs (Taconian and Acadian) are closing on the east coast of North America. The trends of paleocurrents in general fit well with the model, with deposition in marine areas and appropriate source areas. However, deposition in the northeast indicates a significant source of sediment unaccounted for by these models. And continued massive deposits on the craton itself is unaccountable.

Lower Ordovician witnesses the near approach of Taconic terranes to the craton from the east with mixed volcanogenic sediments. A second active margin becomes operative in the Arctic region and remains active throughout the Paleozoic. Paleocurrents represent "nonexistent" source areas and deposition from marine source areas onto land. Both of these arguments would only be consistent if events were occurring on a time scale much different than that generally ascribed to the Phanerozoic.

By Middle Ordovician, most of North America is covered by sediments of the Paleozoic, except for the Shield. The Taconic bodies are approaching rapidly from the east, as is Avalonia and the much larger Baltica landmass. Sediment source areas remain offshore in the east, and again question some features of the model, such as time or placement of the positive areas. It is an important observation that from this time onward, sediment sources and fossil sources will have to be coming from off-continent because the entire craton has been covered with Cambrian and Ordovician sediments. If subsequent deposits were derived from on-continent, they would be recycled sediments, and the Cambro/Ordovician cover would be missing. Likewise faunal elements must be coming either out of the water column or from off-continent (except if the shield is a source for either).

In Upper Ordovician, contact is made with the Taconic Arc, and the oceanic/volcanic sediments overthrust the east coast of Laurentia, generating the mountains of the Appalachia. Avalonia is in imminent contact with Baltica. And the Iapetus Ocean is narrowed in the north. Western North America continues a passive margin (no major tectonic activity). Paleocurrent trends still show a prevalence of westerly directed sediments, but as the mapping indicates, source areas still appear to be oceans and deposits of marine sediments appear to be positive areas on the craton for many of the deposits. This is anomalous. This is the end of the Ordovician.

Lower Silurian shows considerably more positive relief than the Ordovician, and with the arrival of the Taconic sediments, a wealth of positive relief is present in the east as a source for sediments. The western interior is dominated by carbonate sedimentation (which will not show up in paleocurrent maps usually). Iapetus Ocean is now closing in the north as Laurentia collides with Baltica-Avalonia. Paleocurrents reflect a strong input of freshly derived sediments from the east, now justifiably, with the recent impact of the Taconic.

Upper Silurian continues the trends of the Lower Silurian. The North Iapetus is now completely shut by early phases of the Caledonian Orogeny. A complex of microcontinents rifted from Gondwana in the south (Hun Terrane) approaches Laurentia from the southeast. The still-passive western margin of North America is about to change as Antler complex approaches from the west. Paleocurrent data reveals a remarkably consistent source for these sediments, including a new source in the south for westerly derived sediments.

Continuing to Lower Devonian, we can see significant suturing of continents as the Caledonian-Acadian mountains form in the northeast, and farther east a new land area is accreting, beginning the supercontinent Laurussia. The string of Hunic terranes from Gondwana accretes to the east coast complex, and the Antler Arc continues its eastward march toward the west coast. Paleocurrents still show a dominant westerly transport of sediments.

Middle Devonian shows the continuing Caledonian Orogeny, now with a left-lateral shear. Antler sediments begin the conversion of the west coast from passive to active, and continued accretion of additional Hunic elements on the east coast closes the central and southern Iapetus Ocean leaving the Rheic Ocean now separating Laurussia from Gondwana. Note the equator still passes through North America, but some rotation to the left has occurred. Strong westerly directed paleocurrent trends reflect the continued activity in the east.

Upper Devonian shows huge collisional activities in the Arctic as fragments of Siberia collide with northern Canada, forming the Ellsmerian Orogeny. Antler collides with Cordilleran margin of west coast, thrusting passive margin deepwater deposits over the top of coeval shelf carbonates into central Nevada in the Roberts Mountains Thrust. Most of central North America covered by marine carbonates except in foreland basins where thick siliciclastics accumulated, clearly seen in the paleocurrent data.

Lower Mississippian is marked by the closing of the Rheic Ocean as Laurussia and Gondwana approach. Rearrangement of elements from the Hun Terrane occurs along the eastern margin, while other Hunic elements collide with the southern boundaries to form the Ouachita Orogeny. Distal to the active margins, massive carbonate deposition is recorded. Paleocurrents showing source areas in the eastern active margins are still mostly westerly directed.

Upper Mississippian shows tremendous change as eastern North America collides with the African component of Gondwana, initiating the Alleghenian Orogeny. West coast collision with the elements of the Antler initiates an easterly dipping subduction zone, and elements of the Antler become the leading edge of western North American (Stiking and Quesnell and Roberts Mountains Allochthon Terranes). Paleocurrents show huge amounts of westerly directed sediments flooding the craton from the east, but also some easterly directed sediments being shed from the recently acquired Antler terrane.

Lower Pennsylvanian reveals continuing suturing between Laurussia and Gondwana as the Pangaean landmass forms. Appalachian-Ouachitan Orogenies continue. More of the Hun Terranes accrete along Southern Europe. The Tethys Ocean, separating Gondwana from Asia, was created out of remnant of Rheic Ocean after suturing of Laurussia and Gondwana forced it eastward. Sedimentation across the North American Craton is now mostly siliciclastics, and westerly directed except for the west coast where continuing influence of the Antler is evident.

Upper Pennsylvanian shows the uplift of the enigmatic Greater Ancestral Rocky Mountains beginning mid-continent and apparently greatly influencing the pattern of sedimentation as new sources of sediments are liberated by the uplift. Sediments continue to be overwhelmingly siliciclastics, some of which are beginning to be interpreted as aeolian. Significant rearrangements of west coast terranes occur under influence of transform faulting.

Lower Permian sees the completion of the assembly of Pangaea. Many deposits on the craton are described as aeolian or fluvial. The west coast along with Arctic (north) are now the active margins. Offshore terranes continue to move toward west coast, accreting limestones on the margin. Paleocurrents reflect a mostly south and easterly direction, in the west. No (remaining?) Permian sediments deposited in most of North America, which is presumably not under marine influence at this time.

Middle and Upper Permian show very little tectonics. Offshore on the west coast, exotic terranes dance, but do not change much during these intervals. Likewise, sediment deposition is stable and constrained to a small region of North America with little change in direction throughout. This brings us to the end of the Paleozoic, and one of the greatest extinctions in the history of the planet. By the end of the Permian, 95% of all Paleozoic species are extinct. While there is much speculation as to why this is so, the paleogeographic maps make clear that marine organisms did not exist in environments where they could be buried over much of Pangaea (no marine sediments). The environments in which Paleozoic animals and plants lived, the sources of our sediments and fossils, were all gone by this time, and marine organisms from now on are going to be from a new environment, the global ocean.

The Mesozoic

The Triassic continues the tectonic stagnation of the Permian, with most of the action centered off the west coast where a complex series of fore arc, fringing arc, and inter arc basins accumulate sediments in what will ultimately be the Cordilleran subduction. The equator is now well south on the craton, and rotation continues to bring North America into its present orientation. Lower Triassic paleocurrents (and sediments generally) are still limited to the west and are westerly directed. Middle Triassic continues this trend. Only in Upper Triassic do we see substantial sedimentation and that is largely in the Chinle-Shinarump complex, an extensive, but very thin deposit covering 80,000 square miles and supposedly a fluvial deposit. Also noteworthy are the southerly directed currents in the northeast.

The Lower Jurassic shows the beginnings of rifting in the Atlantic basin, that will ultimately lead to the rifting of North America free from Pangaea for the first time. By now the Appalachians are well eroded away. Western North America is rapidly accreting its west coast by collapsing of back arc basins against the continental margin. Wrangell and Guerrero Terranes are approaching the west coast. Ultimately these will collide with the coastline to form Klamath Mountains and parts of the Sierras. The Cordilleran Arc experiences a major magmatic episode. Paleocurrents are predominately westerly directed, even along the newly opening Atlantic margin where easterly directed deposition would be expected.

Lower Middle Jurassic shows a continuation of the rifting of North America from the Pangaean supercontinent. A relatively sudden shift in paleocurrents from predominantly westerly to predominantly easterly for the balance of time, is seen first in this view.

Upper Middle Jurassic shows for the first time a completely rifted North America and the opening of the proto Atlantic, as well as the rifting across the south, beginning the opening of the Gulf of Mexico. The Yucatan Peninsula upon which Cancun sits is rifted southward out of the Gulf of Mexico. On the West coast, Wrangellia and Guerrero terranes continue to approach and intra arc and inter arc flysch basins accrete sediments offshore. Early phases of the Franciscan Melange are forming offshore. Another major development seen first here is the opening of the Western Interior Seaway in the heart of the continent. Rocks such as the Navajo Sandstone continue to be seen as aeolian. Paleocurrents are eastward directed into the opening Seaway, and westerly directed offshore, patterns we shall see for the duration, in the west.

By Upper Jurassic, the Mid-Atlantic rift has continued to widen setting North America free. Movement to the west has hastened the approach of the Wrangellian and Guerrero Terranes toward the west coast. The Western Interior Seaway has narrowed and moved north. Paleocurrents are directed onto the craton.

Moving now to the lower Lower Cretaceous, additional triple junctions are initiated by the rapidly spreading Mid-Atlantic Ridge. The Western Interior Seaway has retreated nearly off the craton. The Nutzotin Ocean has been formed between Canada and Wrangellia. Paleocurrents are westerly directed along the craton margin, and along the eastern margin of the former Seaway.

In mid Lower Cretaceous, the Atlantic continues to widen and Western Margin paleocurrents are directed offshore.

With the upper Lower Cretaceous, we find the Western Interior Seaway has once again advanced, this time occupying most of the interior of the craton, and nearly bisecting North America. The Guerrero Arc is accreting to west coast. Southward-moving Wrangellia has captured the Northern Cascades and adjacent terranes to form the Baja-BC terrane, a huge mass of exotics that will make up a great deal of the west coast. The Great Valley sediments are accumulating in the forearc basin of the Cordilleran margin. Paleocurrent patterns are scattered, perhaps indicative of the tremendous surge in activity in this stage.

Middle Cretaceous is one of the most significant points in the geologic column. It is precisely here that we first record the presence of flowering plants, the angiosperms, in the fossil record. What was happening before this time and what possible change could have occurred here that resulted in the sudden influx of flowering plants into the sediments for the first time? Flowering plants are essentially all of the plants we see around us today. Their absence up to this point and their sudden appearance after this point is what Darwin termed "an abominable mystery." Are there any clues in the paleogeography or paleocurrent data that may help us resolve this question? Or, does the presence of the angiosperms tell us something about the mode and source of sediments that we cannot learn from the paleogeographic or paleocurrent data? These are important questions that will reflect on the usefulness of the exercise we are engaged in.

In mid Cretaceous, the exotic terranes of the west coast are fully approximated to the craton, the Atlantic Ocean is open and mature, the westward migration of the Arctic terranes now comprise the future Siberia, and the continued expansion of the Mid Atlantic Ridge begins to separate Greenland (paleocurrents are from previous stage).

Lower Upper Cretaceous reveals a western interior Seaway that completely bisects North America. Meanwhile, the southern movement of South America widens the Caribbean Sea. Complete suturing of the Wrangellian Terrane all but eliminates the Nutzotin Ocean in the northwest. The Arctic Basin is completely open now as Siberia forms to the north. What will be the Great Valley Sequence continues to build in fore arc basin as does Franciscan Complex. Paleocurrents indicate transport into the Seaway and off the coast as before.

Middle Upper Cretaceous reveals a North American plate with an Andean-style cordilleran arc stretching from Chile to Alaska. The Baja-BC complex has moved as far south as it will go. Paleocurrent patterns reveal close relationships to source rock possibilities, but do not explain sudden emergence of Angiosperms. Note the very precise fit of paleocurrent data to the southeastern margin. Western paleocurrents are still directed offshore as before.

Upper Upper Cretaceous events include the closing down of the Seaway bifurcating North America, the reversal of the southward movement of the Baja-BC complex, forming among other things, the Coast Range of California on the Complex. The Arctic Ocean is now completely open as is the Atlantic. Final phases of Great Valley Sequence are deposited in the fore arc basin. Paleocurrents are largely easterly directed across the Seaway, and westerly directed offshore where the 5000 feet of turbidites that will make up the Great Valley Sequence of Central California are accumulating. This brings the Mesozoic to a close. With this closure comes another major extinction. On land, the last of the living dinosaurs disappears. In the ocean, the last of the class of mollusks called Ammonites disappears. Many other forms disappear. But other groups seem to have been untouched. A putative impact centered near Cancun just off the Yucatan is supposed to have been the event that triggered the end of the Cretaceous. The evidence for that is questionable: A plot of paleocurrents for the Cretaceous-Paleocene interval shows no change from Upper Cretaceous.

The Cenozoic

The Paleocene map shows a recognizable land mass, not too different from North America today. Passive margins exist along both the Gulf of Mexico and the Atlantic coastline. Greenland rifts itself free with accompanying orogenies in the northern reaches. Early phases of Rocky Mountain uplift now begin. The Gulf of Mexico area is filled with thousands of feet of sediments derived from the Mississippi basin. Paleocurrents reflect uplift of Rocky Mountains, and continuation of the off-continent trend along the coast.

Lower Eocene is marked by the accretion of the Olympic Peninsular terrane. The California borderlands are still actively accumulating thick basin fill. Paleocurrents appear less well organized than previously, particularly in the Rocky Mountain region. Sediment along the entire west coast is now being transported offshore (westward) into the fore arc basins.

Upper Eocene continues to reflect the influence of the Rocky Mountains uplift, which is intermittently rising during this period. Paleocurrent patterns are being affected by this emerging mass. Offshore deposition remains the rule along the west coast.

Oligocene shows North America maintaining passive margins along the Gulf and Atlantic coasts. Basin and Range extension faulting begins in the west, accompanied by basaltic magmatism in the Colorado Plateau. The craton is still pouring sediments into the Gulf region, and with the continued activity of the Laramide and uplift of the Rockies, a continuing source of sediment is accessible to the foreland basins (Uinta, Green River) and the plains to the east. Paleocurrents demonstrate the consequences, with easterly directed currents east of the Rockies and westerly directed sediments are still accumulating in the Great Valley basins along the Cordilleran rim offshore.

Lower Miocene data reveal a continuation of the processes of Oligocene. The Antilles Arc (Cuba, Dominica, etc.) is migrating northward into the Caribbean. Northward migration of terranes of the Baja-BC complex completes the arrival of the Alaskan exotics. Paleocurrents reflect activity in the Basin and Range region and continuing offshore movement of sediments.

Upper Miocene sees subduction along the Pacific coast, and westward movement of the Pacific Plate. Eastward movement of North America from the Mid-Atlantic Ridge causes overriding of subduction zone by North America. Consequently, sediments of the Great Valley Sequence and Franciscan Mélange are accreted to the west coast. Right lateral movement along the Pacific coast continues. Paleocurrents appear not to be controlled by global processes, but local exigencies. Offshore sediment transport continues unabated along the west coast.

Pliocene events include the development of the Gulf of California as an outlet for the Colorado River through continued right lateral movement along the San Andreas system. Great Valley system is now emplaced in the Central Valley of California, 7 km of vertically arrayed turbidites accreted from offshore by westward migration of North America. Siberia and Greenland are freed from contact with North America in the north. Paleocurrents still show offshore movement along the west coast, but locally arrayed vectors are distributed in many areas.

And that brings us back to the present. On our journey, we have seen North America split off from a southern megacontinent early, move off to the north, begin with a passive west coast and active accreting east coast. Midway through the column, the land mass united with Gondwana remnants to create a second megacontinent, Pangaea. North America then broke from Pangaea, taking with it portions of Africa, and moved farther to the north, rifting off Europe, Great Britain and Siberia. Finally, through a complex set of accretionary processes North America acquired the west coast we know today, scraping off the ocean floor California, Oregon, Washington, British Columbia and Alaska.

Conclusions

At the beginning we asked "If we could devise a technique to reconstruct past geologic events on a grand scale what would we learn?" "What questions could we ask?" "What answers would we have?" "What other questions would arise?" We have just walked through one representation of the history of the world. While paleogeographic details are subject to change, the general picture we have seen is consistent with some lines of evidence. What we have described is that land areas we may in the past have thought of as stable, have been undergoing repeated assaults by foreign terranes and collisions with other cratonic masses on a hugely dynamic scale. We have described paleocurrent data suggesting that massive catastrophic depositional processes accompanied the tectonics of the past. These kinds of depositional processes are not taking place anywhere on the earth's surface today, except perhaps in deep ocean basins. Huge complex areas of marine deposition occurring on-craton unlike anything happening today reminds us that the present is not the key to the past. Why have sediments remained on the continents if there were ocean basins just offshore? Why do we still have huge accumulations of Cambrian sediments on the North American continent if hundreds of millions of years have transpired for erosion to work? Why do the sediments of the Paleozoic move from east to west across the craton regardless of the paleogeographic orientation of the craton? Some of these observations challenge the time frame for deposition, some challenge the paleogeographic reconstructions, but all suggest we are far from having final answers within the Standard Model.

At the same time, questions arise that challenge us to further study. If, for example, post Taconic sediments are derived from the Appalachians, why do the fossil fauna in the redeposited sediments agree with the time of redeposition rather than the time of initial deposition? Where are the fossils derived from? Where were all the angiosperms while the sediments below Upper Cretaceous were being deposited? There was no obvious change in tectonics or paleocurrents at mid-Cretaceous to helps us out. Or was there? Is it possible that plate tectonics offers an explanation that can help us? The concept may indeed help us answer some questions. Suppose that what we are interpreting as exotic terranes being accreted to the margins are really the remnants of the tectonic "vehicles" that delivered successive waves of source rocks and fossils to the depositional centers. When the Upper Cretaceous arc arrived it could be recognized by the fossils it transported. This could explain why the Upper Cretaceous flora and fauna are only found after the arrival of the appropriate terrane.

What about the time frame? Can the suite of events we have just considered happen on a time scale much shorter than that generally assumed? Baumgartner has suggested (2) the answer is yes. He elaborated a geophysical model for runaway subduction and offered support for that assertion. Geophysicists detected subducted slabs at the core-mantle boundary that were still "cold." This could only happen if the rate of subduction were orders of magnitude faster than at present.

While unanswered questions remain, we have many suggestions of places to look. What will we find when we compare tectonics and paleocurrents on a global scale? The journey is just beginning!

References

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