Large cratonic basins likely of impact origin

Michael J. Oard

Cratonic basins are mysterious features of the interior of continents. A saucer-shaped feature filled with sedimentary rock is formed but the mechanism of subsidence is unknown. These basins have collected thousands of metres of sediments that in most cases have received little deformation until uplift. Moreover, these basins commonly have thinned crust and an uplifted mantle underneath, and the said crust has relatively high density. Such features are amazingly similar to what is expected after impacts. A brief description of the Belt, Williston, Illinois, Michigan, and Hudson Bay Basins of North America shows that these basins fit an impact origin. Two other amazing basins from other continents, the South Caspian and Congo Basins, also described, can readily be explained by large impacts.

Basins are geologically defined in four ways.[1] The first is a *topographic basin* such as the Great Basin in the western United States that has interior, closed drainage. The second type is a *structural basin* in which the strata dip toward the centre of the basin (see figure 8b). The Williston Basin in eastern Montana, western North Dakota, and adjacent Canada is an example. The third type of basin is the *drainage basin*, such as the Mississippi River Basin. And the fourth type is the *sedimentation basin* where thick sedimentary rocks accumulated, such as the Appalachian Basin in the eastern United States, and have been partially uplifted (see figure 8d).[2] This paper will discuss only the second and fourth types, which I will just refer to as 'basins'.

The subject of basins is huge with many variables defining a basin. For instance, basins vary in shape, depth of sedimentary rocks, and geophysical properties. There probably are multiple causes for basins. Bolide impacts have been considered as one of the mechanisms for many approximately circular basins,[3] such as the Williston Basin.[4]

I will first show that uniformitarian scientists do not understand the origin of these basins. I will then review information on impact basins and show how impacts can account for many of the features of continental interior basins that are assumed to be *stable* tectonically and unaffected by plate tectonics.[5] These continental interiors are also called 'cratons' and the basins called 'cratonic basins'. Impact basins are most likely to survive the Flood on such stable cratons; Flood tectonics, volcanism, erosion, and sedimentation in other areas are more likely to destroy impact craters. I will give several examples of likely impact basins from the approximately 600 examples on the continents.[6] About 200 of these basins have diameters greater than 300 km.[7]

Uniformitarian origin of basins unknown

One would think that after over 200 years of uniformitarian thinking, the origin of continental basins would be known, but this is not the case. One of the main problems is the failure to understand why the basin subsided to collect all the sediments. It is no wonder that in the preface to a 2009 volume of the journal *Tectonophysics*, summarizing the progress in understanding sedimentary basins, scientists admit there still is "poorly understood subsidence dynamics of intra-continental basins".[8]

How does the basin subside?

The main issue is how a basin subsides for hundreds of millions of years of uniformitarian time on a stable continent. Although there are many suggested mechanisms, two popular models to explain basin subsidence have been in vogue: (1) thermal subsidence of a cooling mantle plume head and (2) a phase change to a denser mineral in the lower crust and upper mantle.[9] But there are two major problems with the thermal subsidence model. Firstly, the area should have *uplifted* as a hot plume rises to the surface prior to the subsidence, but there rarely is any evidence for this.[9,10] Secondly, as the area cools, space is needed for subsidence if there is no lithospheric stretching.

The crustal stretching problem

Dan McKenzie proposed that as basins slowly cool, lithospheric stretching thins the crust to allow further subsidence: "Both the space and the heating problems [with other models] are avoided if the basin is produced by stretching the continental crust over a large region."[11] McKenzie adds:

> "The obvious objection to this suggestion is the amount of extension required: about a factor of two to produce a basin filled with 4.5 km of sediments. If the model is correct this extension must generally have been overlooked."[12]

Notice that McKenzie believes that the extension in and around the basins must have been significant but overlooked. It is "overlooked" because there apparently is little or no evidence for such large stretching of the crust.[13,14] This is a major problem with uniformitarian models. Russian geophysicist

Eugene Artyushkov states: "In many intracontinental basins crustal extension amounts to only a few percent and is unable to explain their subsidence".[15] Prijac *et al.* write:

> "However, these [stretching] models are still debatable. In particular, in many intracontinental basins, they show strong discrepancies between the amount of extension, measured on fault planes or deduced from crustal thickness, and the stretching ratio predicted by the subsidence analysis."[16]

Extension, as well as rifting, are unlikely as the cause of cratonic basins:

> "Large-scale basins form a separate class of basins that are less well understood and show different characteristics and are often called cratonic or intracratonic basins [references deleted]. This terminology reflects that their evolution is not clearly related to rifting or in general extension but that they are of a large-scale."[17]

Phase change problem

The mechanism of phase change seems to be the only viable uniformitarian mechanism for basin subsidence. For instance, if basalt or gabbro subside, the lithostatic pressure increases and the rock can change to eclogite, which is 15% denser with 15% less volume. The required pressure is that of the lower crust and upper mantle. So if basalt and gabbro can subside to about 40–60 km depth, this phase transformation can potentially occur and the basin will subside more. This is a reasonable idea, except where does the initial subsidence come from? Furthermore, the phase transformation from gabbro to eclogite requires water,[18] and there is rarely any significant water at the depth of the lower crust and upper mantle.

Artyushkov favours phase change for many basins, possibly because none of the other mechanisms has any significant evidence. However, other scientists say there is no convincing petrological and seismic evidence for a thick layer of eclogite in the lower crust or upper mantle in cratonic basins.[19]

So, basin subsidence remains a major mystery of continental basin formation. Heine *et al.* conclude that five non-exclusive mechanisms to explain the long-lasting subsidence of basins over hundreds of millions of years all fail: "However, these hypotheses fail to explain the observed subsidence patterns of large intracontinental basins within a coherent global geodynamics framework." [20]

Properties of basins

Although the origin of basins is mysterious within the uniformitarian paradigm, basins display a number of interesting properties that I will later show are consistent with an impact hypothesis.

Thick sedimentary rocks

Basins are almost always filled with sedimentary rocks, which are sometimes extremely thick. Some depths will be given in the examples of basins below, but other basins not mentioned are the East Barents Basin in the Barents Sea, north of Norway, that has about 20 km of sedimentary rocks; the West Siberian Basin with about 8 km of sedimentary rocks; the Tarim Basin of central Asia with 15 km of sedimentary rocks; and the Paranà Basin in South America with about 7 km of sedimentary rocks.[21]

Little deformation during sedimentation

An examination of those rocks reveals that the sediments underwent little deformation when deposited in the basin.[13,22] Figure 1 shows sedimentary rocks of the Precambrian Belt Supergroup, which are typically undeformed within the bedding planes and formations, but the whole supergroup is deformed as a single unit, suggesting that deformation occurred *after* the whole supergroup was deposited. For instance Carroll *et al*. state: "Central Asia contains numerous closed geomorphic basins that are surrounded by active mountain ranges, but exhibit little internal deformation."[23] This is indeed strange if the basins were actively sinking. Kaus *et al*. point out: "The most prominent difficulty is that many basins have relatively thin syn-rift sediments, but thick post-rift sediments."[24] Syn-rift sediments are those sediments deposited while the basin is opening and are probably recognized by once being deep in the basin and deformed. The majority of sediments are post-rift sediments, deposited with little deformation after the basin has fully formed. It is as if the basins formed quickly and sediments quickly filled

Figure 1. The 300 m high 'Chinese Wall' along the continental divide of the northern Rocky Mountains of Montana showing little deformation of the strata. The lower strata are composed of Belt Supergroup sedimentary rocks ('dated' 1.5 Ga) while the upper strata are composed of Cambrian sediments ('dated' 520 Ma) within the uniformitarian geological column.

them with little movement of the basin walls and bottom during the majority of the sedimentation.

The crust is commonly thinned in basins

It has been discovered by seismic and gravity anomaly methods that the crust below a basin is commonly thinned. Artyushkov states: "Considerable thinning of the crystalline crust occurs under most deep basins located on continents."[15] Along with a thinned crust, the Moho, the boundary between the crust and mantle, is commonly raised (see figure 2).

Some basins uplifted and deformed

Another significant observation on basins applies to sedimentary basins in which the sedimentary rocks are uplifted and folded by compression and differential vertical tectonics.[22] Practically all uplift occurs after the sediments have been deposited and turned to sedimentary rock. During uplift, the sedimentary rocks are folded and faulted with the top eroded. Such uplifted sedimentary rocks form many of the mountain ranges of the world today and would not impress anyone that they were once in a deep basin.

The crust may have a relatively high density

It is significant that the density of the crust is higher than expected, based on seismic waves.[25] It is however not dense enough to be eclogite.

Impact basins after the first hour

Before I make a case that impacts likely caused cratonic basins, I need to review the unique processes of asteroid or comet impacts.[26] The immediate effects are generally complete within the first hour.[27] Bodies greater than ~100 m will pass through the atmosphere unscathed. Large to very large impacts that cause basins greater than 300 km are complex with many unknowns. They behave differently than smaller complex craters. The effect on the solid earth's surface is the same with large impacts in water, except for the blasting of a great amount of water upward in the atmosphere and the tsunami that occurs. Water ejected into the atmosphere (or higher) would spread around the earth and fall back as intense rain. This provides a potential mechanism for the Bible's 40 days of rain.[28] So, it does not matter whether a larger impactor hits water or land.

A large transient cavity is first formed within seconds of the impact. Whereas the depth of the transient cavity is about ⅓ to ¼ the diameter in simple and small complex craters, the ratio is much less for large and very large impact craters. The reason for this is not clear. It is known that right after the transient crater reaches a maximum volume,

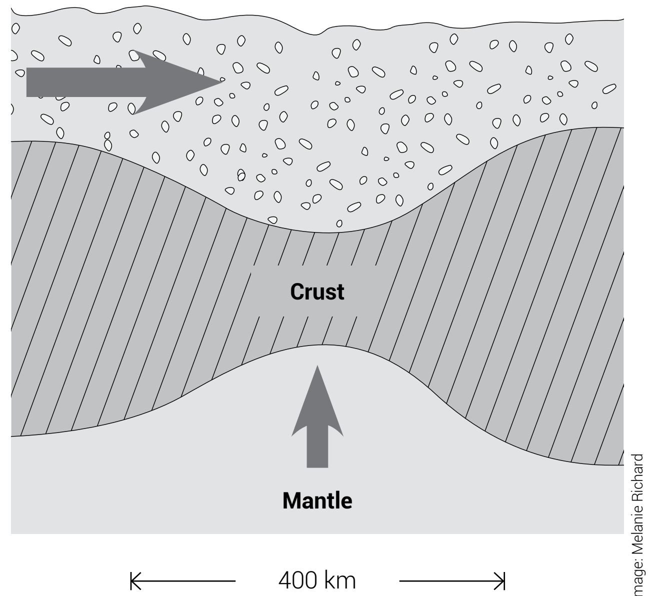

Figure 2. Schematic of the thinned crust and uplifted Moho, the boundary between the crust and mantle, typically beneath an impact crater right after formation.

the bottom rebounds upward quite high as a central uplift and settles back down into the crater.[29] The rock acts like a fluid and several more up and down oscillations can take place. At the end, there is usually no central uplift when the crater is greater than 300 km, but the crust is thinned and the Moho is usually raised.

At the same time a crater rim is formed by pushing out the rocks, but soon after the walls of the crater collapse partially inward, making the crater significantly larger. A saucer shaped three-dimensional profile results with uplifted, thrusted, and/or deformed rock at the edge of the crater.

Slow modification of impact basins after one hour

The saucer-shaped profile will remain relatively stable for a short period and may either subside or uplift depending on other variables, such as whether a phase change occurred in the lower crust or upper mantle caused by impacting, the temperature of the rock, and the type of rock. Generally, the impact crater is out of isostatic equilibrium from losing portions of the crust and will tend to uplift with time. On the other hand, if the oscillations of the central uplift stopped too soon, the Moho can be considerably raised with a high gravity anomaly, such as the mascons on the moon. Such basins will subside with time.

Many other variables will determine the amount of uplift or subsidence of the impact crater after the first hour. Rapid uplift in a matter of days to weeks can occur soon after a

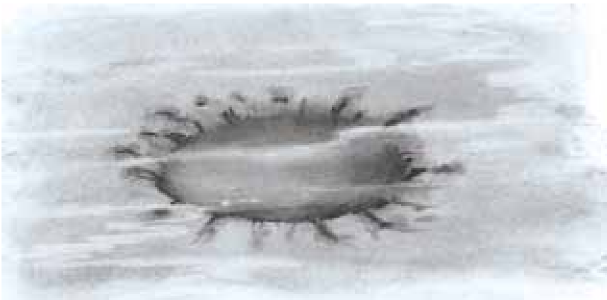

Figure 3. Simple schematic of the three-dimensional saucer shape of a typical cratonic basin.

basin is formed; it does not take thousands to millions of years. If the crater is strongly out of isostatic equilibrium and if the temperature is high at the bottom, the crater will rebound upward at a relatively rapid rate. By this time, it could be filled with sediments.

Impacts can explain the properties of continental basins

Mainstream scientists rarely suggest an impact origin for continental or cratonic basins, perhaps because they believe plate tectonics is the primary driver of crustal configuration. Nevertheless, impacts can amazingly account for the major features observed or inferred in interior continental basins. I will summarize features favourable to an impact origin for large continental basins.

Large cratonic basins are saucer-shaped

The first thing to note is that many of the large basins in the interior of continents are generally circular in plan view and saucer-shaped in three dimensions (see figure 3). For instance, Hudson Bay Basin in the middle of the Canadian Shield is approximately circular in plan view.[30] Heine *et al.* state: "Most basins show a circular pattern, indicating more tectonic subsidence in the basin center."[31] Morris Leighton writes: "As Bally (1989) notes: 'the deceptively simple cratonic saucers of our continent remain unexplained.'"[32] Armitage and Allen further write:

> "However, extensive regions of stable continental lithosphere have experienced prolonged subsidence, interrupted by phases of uplift, forming large saucer-shaped sags or basins."[33]

The shape of these cratonic basins is what is expected for impact structures.

Instant basin with little or no stretching

The crater represents a quick loss of part of the crust forming an instant basin *without* much stretching of the lithosphere surrounding the basin. Subsidence of basins is one of the basic features of basins that cannot be explained by uniformitarian scientists. In the case of an impact origin, no subsidence is needed to form the basin; an instant circular 'hole' in the ground is blasted out. Subsidence or uplift may occur after the basin is filled with sediments.

Crust thinned with higher density

At the same time the crust is automatically thinned with the loss of the top portion. The remaining crust would be of higher density than the top portion of the crust, since the crust increases in density downward. An impact melt layer is also expected to form at the bottom of the crater, and after it cools could also account for higher seismic velocities of the crust in continental basins today.

Surrounding areas uplifted

It is not unusual to find the surrounding area of a basin uplifted, such as the area surrounding the Kalahari Basin in southern Africa.[34] Folds and overthrusts are expected to occur along the rim of a large impact.[35] So, mountain ranges can be expected around some basins, and indeed this is the case with many basins.

Basin quickly filled by sediments

After the first hour, the basin is modified very slowly. This gives time for the hole to collect a great amount of sediment. With one isolated impact, extensive filling of sediment from outside the crater seems unlikely. However, the Flood impact submodel postulates thousands of impacts occurred early in the Flood. One major effect of such a large amount of impacts is to blast a huge amount of debris up into the air in the form of ejecta. All this sediment would end up in the floodwater and would eventually be deposited.

A second major effect of so many impacts is that powerful currents would develop, sometimes interfering with each other. So, the combination of powerful currents and a huge amount of sediment would be rapid sedimentation in deep basins where currents are expected to be weaker and allow sedimentation. So, early Flood impact craters are expected to rapidly fill with sediments, since the crater acts like a sediment trap (see figure 8a). Sedimentation was likely so rapid that the sediments were little deformed by subsequent movements of the crater bottom and walls.

Some impact basins will uplift

Typically, an impact basin will be out of isostatic equilibrium because of the loss of relatively denser crust compared to the lighter sediments filling the hole. The crater will tend to rise, unless there are forces, described above, that can offset this rising tendency. For instance a phase change caused by the impact could actually cause the basin to subside instead of uplift. That is why the long-term effect of impact basin modification can be variable—either no change, slow subsidence, or rapid rise. Such changes are called relaxation.

Uniformitarian scientists assume relaxation takes thousands of years, but if the rocks are hot, the relaxation can happened quickly. So areas of relatively hot rocks surrounding a crater in the larger basins can relax quickly,[36] while those surrounded by relatively cool rocks would relax slowly.

During the Flood, fast relaxation for craters early in the Flood seems likely because the impacting rate is expected to be greatest, heating up the crust and upper mantle. As impacts decrease during the middle of the Flood and thousands of feet of sediments cover the continents, the rock surrounding an impact likely would be cooler and hence the crater would relax more slowly. This seems to explain why some Precambrian basins filled with many kilometres of sedimentary rock have uplifted during the Flood. A good example is the mid-Precambrian Belt Basin of the northern Rockies of the United States and adjacent Canada, discussed below.

Large basins of North America

There are five large basins on the stable craton of North America that I will briefly discuss. These basins are the Belt, Williston, Illinois, Michigan, and Hudson Bay Basins. I will simply describe the basic dimensions of these basins, the amount of sedimentary rock filling the basin, and possibly add a comment supporting the impact origin of the particular basin.

The Belt Basin

The Belt Basin represents the Precambrian sedimentary rocks that now outcrop as mountains in the northern Rockies of the United States and adjacent Canada (see figure 4). The strata are called the Belt-Purcell Supergroup and are made up of more than 50 formations over an area of about 202,000 km^2. The sedimentary rocks have been greatly uplifted, folded, and faulted with basalt sills and dikes. Based on the dimensions of some folds, the minimum depth of the Belt Basin was 20 km before uplift.[37] However, the bottom has not been found and the top has been greatly eroded, so the actual thickness probably was once about 25 km deep. The sedimentary rocks show abundant turbidites with 'shallow water' fine-grained deposits.[38] The coarse silt and fine sand of most of the Belt sedimentary rocks have been weakly metamorphosed to argillite and quartzite, respectively, probably caused by deep burial.

The basin's dimensions are 400 km by 600 km and show a crude circular shape, but when considering the great Flood uplift of the basin and faulting, some distortion is bound to have occurred. Another factor is that early in the Flood, multiple impacts occurred[39] and so significant distortion of circular craters would occur. There are other factors that would cause an impact crater to be non-circular in shape.[26]

Williston Basin

The Williston Basin, centred near Williston, North Dakota, is an oval-shaped basin about 1,200 km northwest-southeast and 600 km northeast-southwest. It covers about 768,000 km^2 in western North Dakota, northwestern South Dakota, eastern Montana, and adjacent Saskatchewan and Manitoba (see figure 5). The oval shape is not uncommon in large impacts on other solar system bodies,[26] but in this case the deep basin is actually circular with the oblong shape caused by the top sedimentary rocks being part of the general subsidence in Alberta and Saskatchewan of the Western Canadian Basin.[40] The basin contains more than 4,900 m of sedimentary rocks that deepen toward the centre.[41] Abundant oil is being found in this basin, which is not a rift but simply a sag.[40] Uniformitarians claim the basin has been subsiding for a long time, supposedly since the late Precambrian, since they claim the basin has sedimentary rocks from the Cambrian to the Tertiary, although there is much missing time between formations.[42] There has been considerable speculation on the cause of subsidence with extension and lithospheric cooling being considered unlikely. Therefore, the only candidate left is a phase change

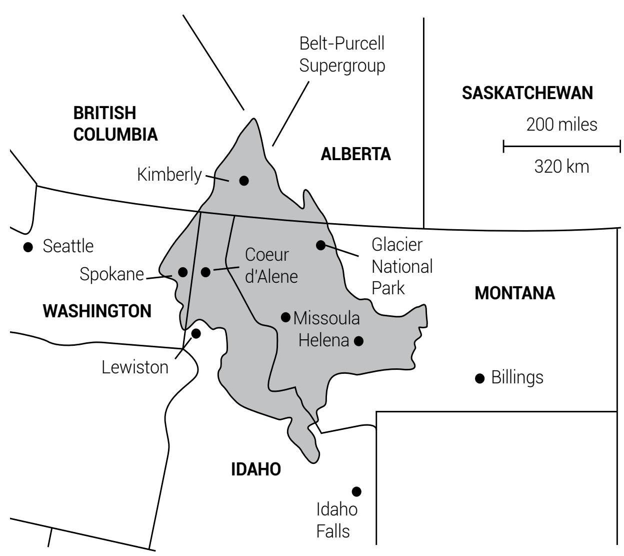

Figure 4. Area of the 400 km wide by 600 km long Belt Basin containing the Belt-Purcell Supergroup uplifted and deformed strata (courtesy of Jim Pearl). The depth of the strata were once over 20 km near the centre of the basin west of Missoula.

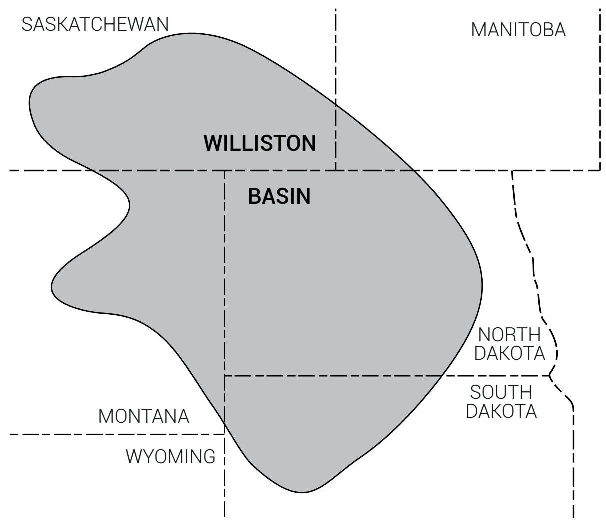

Figure 5. Area of the Williston Basin (redrawn by Melanie Richard). Although the top of the basin is oval, it is circular with depth.

to a denser mineral,[43] which is difficult to explain without a large impact. The Moho is bowed up in the middle of the Williston Basin, typical of modified impact craters.

Illinois Basin

The Illinois Basin is similar to the Williston Basin in being oval-shaped in plan view and saucer-shaped in three dimensions. Its long axis is about 700 km long in a northwest-southeast direction (figure 6). It covers about 280,000 km^2 in southern Illinois, southwestern Indiana, and western Kentucky. This basin is also known for its oil, but the top sedimentary rocks also have been extensively mined for coal. The basin is flanked by domes and arches on the west, north, and east.[44] It has up to 7,000 m of Paleozoic sedimentary rocks.[45] Figure 7 is a cross-section through the saucer shaped basin with great vertical exaggeration. Impact craters are not necessarily circular, but can be elliptical for a number of reasons, especially the larger impact craters.[26] Furthermore, tectonics during the Flood can distort circular impact basins.

Michigan Basin

The Michigan Basin is very nearly circular and contains up to 4,800 m of sedimentary rock.[46] It covers 207,000 km^2 in central Michigan. The origin of this basin, like all the rest, is unknown: "The mode of origin and time of formation of the Michigan Basin are not clearly understood."[47] A phase change from gabbro to eclogite has been the default mechanism to explain the basin subsidence.[48] However, Norman Sleep, apparently frustrated by the special conditions required for a phase change in the Michigan Basin, has developed a model that depends on lithospheric cooling.[49] This mechanism also is unlikely because the basin shows no signs of the uplift that would have occurred during lithospheric heating in the plume model.

Hudson Bay Basin

The part of Hudson Bay with relatively thick sedimentary rocks up to about 2,000 m is very nearly circular with a diameter of about 1,000 km.[30] The crust has been thinned a little with no stretching of the area around Hudson Bay.[50] The origin of the basin of course is unknown but widely debated. However, it fits the expectation of a large impact basin that relaxed quickly, since the sedimentary rock thickness is small compared to other basins.

Two basins of note on other continents

There are numerous basins on other continents, some quite large and deep. This section will describe two of the most outstanding cratonic basins.

The South Caspian Basin

The South Caspian Basin, in the southern part of the Caspian Sea, is a very deep basin filled with sedimentary rocks. The basin is somewhat circular with a diameter roughly 400 km.[51] It is more like 350 km by 550 km.[52]

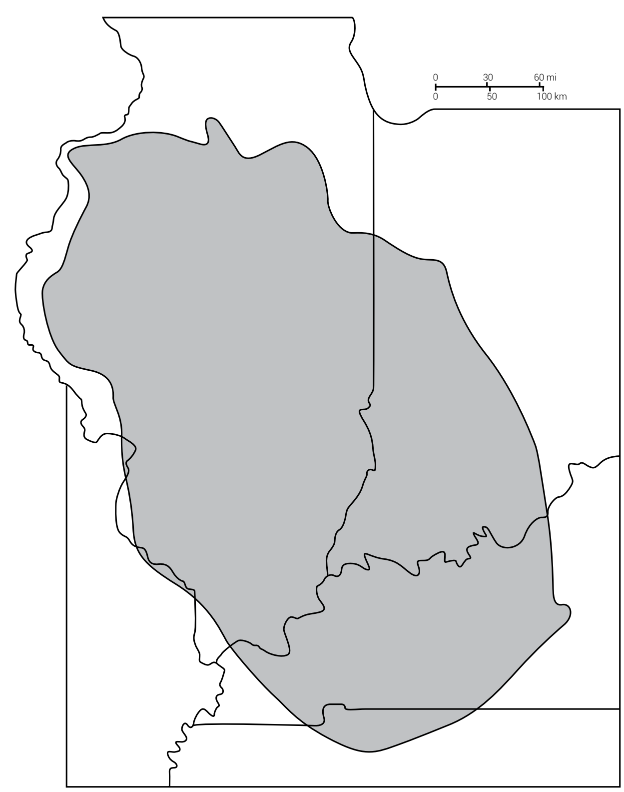

Image: Melanie Richard

Figure 6. Area of the Illinois Basin.

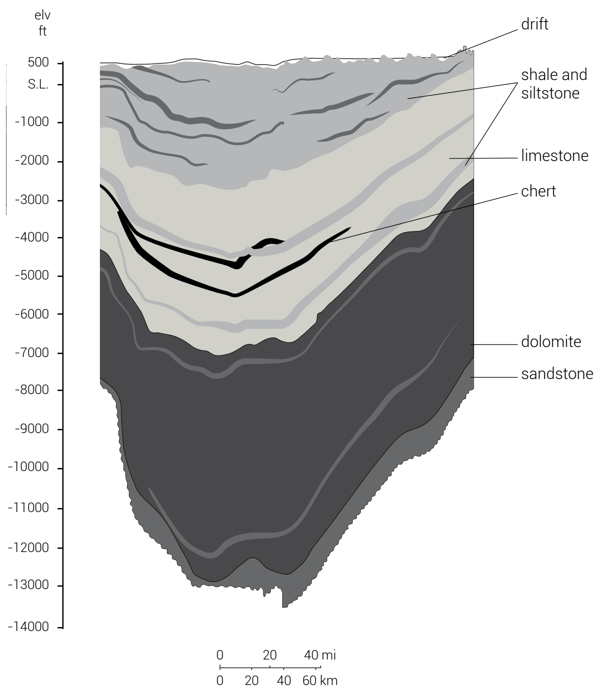

Figure 7. A cross section through the Illinois Basin, southern Illinois and southwest Indiana showing its general crater shape.

This basin has collected probably the world's thickest sedimentary rocks, estimated at 26–28 km thick![53] Seismic profiling shows that the sedimentary layers are generally horizontal with some volcanic rocks.[52] The crust has been considerably thinned to about 10–15 km thick with no hint of extension.[51] That is why a phase change is the suggested mechanism for the huge subsidence required to collect all the sediments. The basin is surrounded by uplifts,[54] such as the Alborz Mountains, Iran, that wrap around the southern part of the basin and are believed to have uplifted about 10 km at the same time the South Caspian Basin subsided.[55] The Greater Caucasus Mountains to the west rapidly uplifted also during basin subsidence.[56] Almost needless to say, this basin and others in this area are a huge mystery:

> "The Caspian Sea basins of Central Eurasia constitute one of the major petroleum provinces of the world (Devlin et al., 1999), and one of the most enigmatic basin systems worldwide."[56]

An impact origin would fit the data quite nicely.

One very interesting feature for creationists is that most of the sedimentary rocks in this basin are considered Cenozoic, with possibly the bottom layers considered Cretaceous within the uniformitarian timescale.[57] The top 10 km are regarded as Pliocene and Quaternary, which is very late Cenozoic![51,58] Within Flood geology, there is a debate on the location of the Flood/post-Flood boundary. Assuming the geological column for the sake of discussion, such huge sedimentation, which was eroded from somewhere and transported into the South Caspian Basin, implies a huge amount of geological and tectonic activity that would fit well with Flood geological activity. How could all this tectonic activity, and massive erosion and deposition of over 20 km of Cenozoic sediments in such a large basin occur in post-Flood time? Furthermore, the sedimentary rocks do not bend steeply into the basin as if the area represented the filling by post-Flood landslides from the surrounding mountains. The sedimentary rocks are generally horizontal and imply rapid sedimentation in water. Therefore, the data favour a Flood/post-Flood boundary in the very late Cenozoic in this area.

The Congo Basin

The Congo Basin is a 2,000 km circular basin in central Africa with up to 9 km of sediments.[59] It covers 1.2 million km^2—10% of Africa's land area! Just like with other cratonic basins the crust has been thinned. The remaining crust has a relatively high seismic velocity.[60] The basin is surrounded by topographic highs interpreted as swells.[61] The stress state in the lithosphere underlying the Congo Basin is compressional, not extensional, similar to the stress pattern for the Williston, Michigan, and Illinois Basins of North America.[62]

The origin of this cratonic basin is of course unknown. The circular shape of this and other basins is a conundrum:

> "The origin of these intracratonic basins has long been controversial. There is *no consensus on the origin of their often circular shapes*, on whether they are primarily extensional and, if so, on the extent to which their subsidence can be explained using simple one-dimensional plate models [emphasis added]."[63]

Uniformitarian scientists are having great difficulty providing a hypothesis on the origin of this basin.[64] A new mechanism suggested is the concept of dynamic topography caused by a "downwelling" mantle circulation.[65] Other scientists think dynamic subsidence unlikely because it is too recent for a basin that has supposedly been subsiding for up to 500 million years.[66]

Other possible explanations for circular structures

Many features of cratonic basins support an impact origin, especially the general circular shape of the basins. However, there are other geological mechanisms that can explain arcuate and circular features.[27,67] These include volcanic craters, diatremes, igneous intrusions, salt domes, tectonic fold patterns, erosional processes, glacial kettle holes, mud diapers, and others. But most of these are of small scale and can be readily identified. Another possible origin for some of the basins might be volcanic craters, such

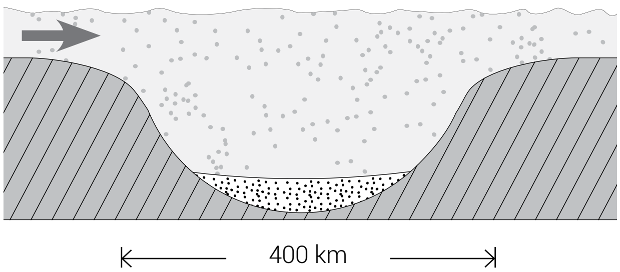

Figure 8a. An impact crater filling and sometimes deforming during the Flood.

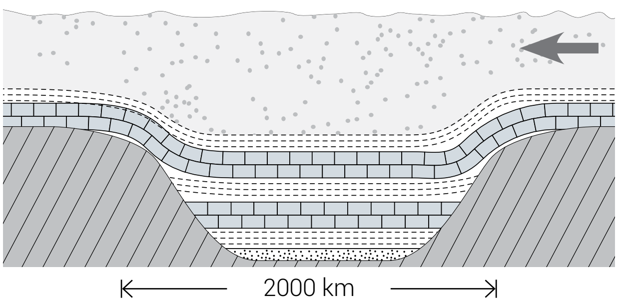

Figure 8b. The transient crater modified a little and filled with sediments.

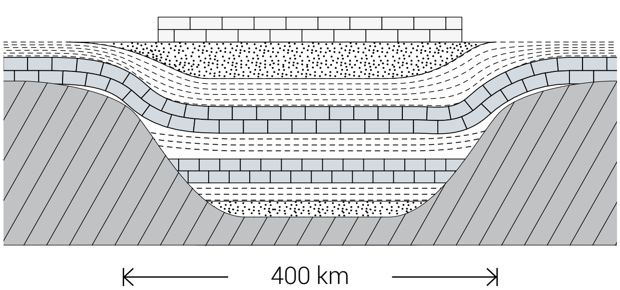

Figure 8c. Structural basin today. The top of the basin fill was eroded during the Recessive Stage of the Flood leaving behind a plateau.

Image: Melanie Richard

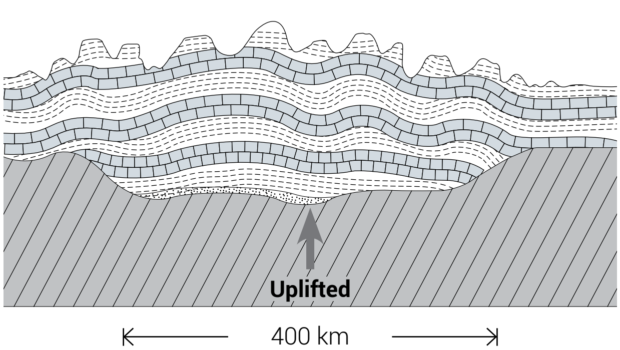

Figure 8d. A sedimentary basin today that, after filling with sediments, uplifted and the top eroded into mountains during the Recessive Stage of the Flood.

as maar craters that do not have a cone or rim.[67] In three dimensions, maar craters can be saucer shaped. This is why it took so long for the small, circular Upheaval Dome in Canyonlands National Park, Utah, to be recognized as an impact crater and not a volcanic structure.[68] But in the case of the large cratonic basins, volcanism seems unlikely because of the basin sizes and paucity of volcanic rocks.

French and Koeberl, in their summary of convincing evidence for impact craters, especially downplayed the significance of circular or arc-shaped features and instead suggested that the only positive evidence for impacts is shatter cones and planar deformation features (PDFs) in quartz or other crystals.[27] However, they admit these features would not be common. Recognizing shatter cones in the field is quite difficult and PDFs would be found only near the centre of impact. They would be absent in the annular zone because the impact pressures decrease rapidly from the point of impact outward:

> "The extreme pressure and temperature conditions of shock metamorphism, and the resulting diagnostic shock-deformation effects, are produced only within a relatively small volume of target rock near the impact point."[69]

Moreover, it is difficult to find planar deformation features in a marine environment. These features can also be misidentified.

French and Koeberl are thinking in uniformitarian terms. They assume isolated impacts separated by millions of years, which would better preserve shatter cones and planar deformation features, although these features might degrade in older impacts. The two largest recognized Precambrian impact features, the Vredefort and Sudbury impact structures, have been eroded anywhere from 5 to 10 km.[70] In a Flood setting, with thousands of impacts in a short time, turbulent currents would be expected to create significant erosion that also would destroy shatter cones, PDFs, and other impact features. The restrictive requirements regarding identification of impacts likely have caused many to be missed. Many suspected impact structures do not meet these requirements.[27]

Discussion

A statistical comparison of cratering records for solar system bodies and earth suggests that earth underwent a much more significant bombardment than is suggested by the geological evidence as understood by uniformitarian scientists. Based on the impact frequencies on the moon, the closest analog, earth should have experienced many thousands of impacts, which very likely occurred during the Flood.[39] There are less than 200 found so far; many more should exist, especially in the Precambrian.

Uniformitarian scientists must be missing many of these impact structures for various reasons. One reason is that the Precambrian has been extensively modified by tectonics, volcanism, erosion, and sedimentation. The Vredefort and Sudbury structures were both severely eroded and deformed. This suggests that the evidence of other impacts would be difficult to find, especially if geologists were not specifically looking for them. Second, secular scientists have stringent requirements for recognition of impacts and hence will miss the vast majority of them. Third, except for cratonic shields, Precambrian rocks tend to be buried by sediments, and are often underexplored because they lack apparent economic resources. Fourth, and perhaps most significant, geologists often see what they expect to see, and miss things that, in retrospect, are obvious. This is a human trait that affects scientists and laymen, noted by many scientists, including Stanford University sleep researcher William Dement with writer Christopher Vaughan: "… even when they are looking, people usually see only what they expect to find and they do not see what they assume for whatever reason could not exist."[71]

The evidence for older impacts may be limited, indirect, and unnoticed by many geologists. A few have pointed this out and noted evidence of other impacts in the Precambrian,[72,73] but finding ancient impacts is still a young facet of earth science. That is why a statistical extrapolation from other solar system bodies may be the best reason to begin to look harder for impacts in both Precambrian and Phanerozoic rocks. One piece of overlooked evidence is cratonic basins.

There are hundreds of cratonic basins that could be discussed, some of which have been discussed elsewhere.[74] Basins on stable portions of continents are a major mystery of uniformitarian geology. Interestingly, impacts can readily account for the major properties of these basins. Uniformitarian scientists rarely consider impacts as the cause of these ba sins because the major impacting of the earth was about 4 billion years ago, and there have been relatively few, isolated impacts since then. It is because of this belief that they look elsewhere for the origin of cratonic basins—unsuccessfully.

Creation scientists, on the other hand, are not constrained by these uniformitarian beliefs. Tectonics, erosion, and sedimentation during the Genesis Flood are expected to destroy much of the evidence for impact craters. But, cratonic basins would be one of the most obvious evidences of large, modified impact craters. Cratonic basins support the impact submodel of the Flood. Figure 8 summarizes these concepts with figure 8c being the structural basin and Figure 8d being the uplifted sedimentary basin as defined in the introduction.

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Michael J. Oard *has an M.S. in atmospheric science from the University of Washington and is now retired after working as a meteorologist with the US National Weather Service in Montana for 30 years. He is the author of* Frozen in Time, Ancient Ice Ages or Gigantic Submarine Landslides?, Flood by Design, Dinosaur Challenges and Mysteries, *and* Exploring Geology with Mr. Hibb.. *He serves on the board of the Creation Research Society.*