23.4° Massive elliptical comet impact craters on Earth.

John A. Burgener,
Telegistics Inc., Mississauga, ON, Canada.
Correspondence:
John A. Burgener, Telegistics Inc.
Mississauga, ON, Canada
john@burgener.ca

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ABSTRACT
Earth is tilted 23.4° relative to the Ecliptic. Tectonic activity can not be influenced by the tilt of the Earth, but comets traveling on the ecliptic can impact at this orientation. It is hypothesized that some comet impacts will have formed ellipsoidal shape craters with the long axis orientated at 23.4° relative to the Equator. These features should fit what would be expected from comet impact origins better than asteroid impact origins, or Tectonic explanations.
All presently recognized impact craters are caused by asteroids. Comets can be larger, faster and less dense. Accordingly, comets will produce significantly different craters.
The Black Sea, Tarim Basin and the Great Lakes are examples of such ellipsoidal features whose origins are difficult to explain by Tectonic processes, and are orientated at 23.4° relative to the equator. The Black Sea is 16 km deep, has minimal earthquakes, and it is filled with flat undisturbed sediments even though it is in an area of mountain building from plate collisions. The Tarim Basin is similar to the Black Sea and also is a flat plain in the midst of plate collisions and mountain building. Lake Ontario and Lake Erie are not oriented in the direction of movement of the glaciers, so it is possible that they are not glacial excavations, and they fit the expected features for a grazing comet impact.
The Hoba Meteorite, weighing 66 tons, was found on the surface with no crater. How it landed gently without forming a large crater is impossible to explain at present. It is predictable that the Hoba should be a sideways splash effect from a comet impact, and that there may be a 23.4° elliptical lake nearby. The Etosha Pan fits as the source impact crater and has a vast splash pattern around it. It demonstrates that this is a valid hypothesis that may be applied to other features on Earth.

INTRODUCTION

1.1 The importance of 23.4°

The Ecliptic is the plane of the orbits of the planets around the Sun. The Earth is tilted 23.4° relative to the Ecliptic. Most comet, asteroid and planet orbits lie on or close to the Ecliptic. Comets orbiting in the Ecliptic are traveling at 23.4° relative to Earth's Equator. As Figure 1A shows, such comets can approach the Earth at 23.4°. The Direction of Travel is different than the Angle of Impact. A comet may hit the Earth straight on, and its angle of impact will be 90° (vertical). Or it can hit a glancing blow, with an angle of impact near zero degrees (near horizontal). For low angle impacts of less than 20°, elliptical craters are produced with their major axis in line with the direction of travel, which can be 23.4° relative to the Equator. As Figure 1B shows, the axis can be either clock-wise or counter-clockwise relative to the Equator, depending on which side of the planet is hit.

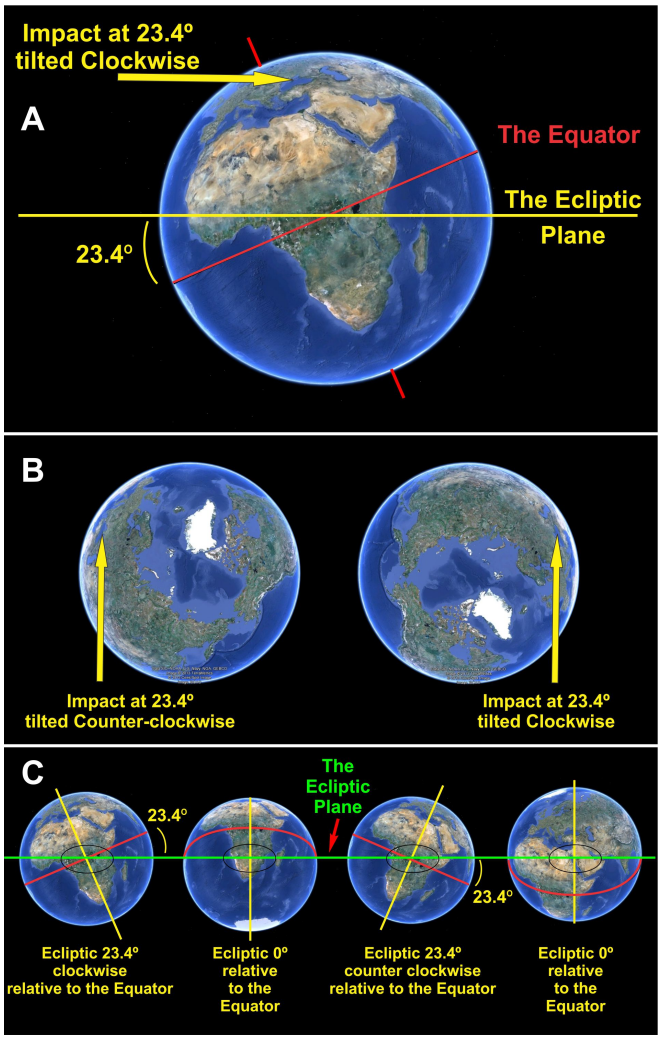

Figure 1: A comet traveling in the Ecliptic can hit at 23.4°, either clock-wise or counter-clockwise depending on which side of the Earth it hits. It can hit the side of the Earth at any angle between 0° and 23.4° relative to the Equator, depending on when and where it hits.

23.4° is the maximum angle likely for a comet traveling in the Ecliptic, as the orientation of the planet can have the Equator angled anywhere between 0° and 23.4° relative to the path of an incoming comet as shown in Figure 1C. Comets that are not traveling in the Ecliptic will impact at random angles relative to the Equator. Of the impacts on Earth, only a very small percentage should be at 23.4°. What is surprising is that so many features are orientated at 23.4°. Those that are orientated at 23.4° are unique in that they can only be explained by a comet impact. Plate Tectonics can not be influenced by the tilt of the Earth.

1.2 Some impacts produce elliptical craters

Most impacts form perfect circles (*Littlefield & Dawson,* 2006, *Elbeshausen et al.,* 2009, *Collins et al.,* 2011). Impacts below 20 degrees usually will form elliptical impact craters (*Bottke et al.,* 2000; *Shuvalov,* 2011), and impacts below 5 degrees will usually be shallow skips. The eccentricity increases as the angle approaches zero. Elliptical craters are rare on Earth with only one recognized: the Matt Wilson impact structure of Australia (*Kenkmann and Poelchau,* 2009). It is calculated to be from an impact between 10° and 15°.

Pierazzo and Melosh (2000) calculate the probabilities of impact at various angles. The probability of an impact at 5° or less is is 0.76%. For impacts between 5° and 15°, the probability is 6%, and for 5° to 20°, the probability is 11%.

The exact angle of impact that leads to an elliptical crater depends on the size and speed of the impactor and the material impacted (*Bottke et al.,* 2000). For most studies the impacting speed is assumed to be less than 25 km/sec corresponding to asteroid impacts. For this paper, comet impacts are being proposed, traveling at 60 – 75 km/sec. *Bottke et al.* (2000) and *Collins et al.* (2011) point out that larger impactors will produce elliptical craters at higher angles than smaller impactors. The craters being reviewed in this article are significantly larger than the 100+ km craters referenced in their papers as large enough to be more likely to be elliptical. Therefore the actual transition angle between circular and elliptical massive craters may be as high as 30°. This would significantly increase the probability of finding elliptical craters on Earth since impacts 30° to 5°

have a probability of 24% according to *Pierazzo and Melosh* (2000).

The exact angles of the impacting features in this paper are not determined, but they are probably in the 5° - 10° range to account for their high eccentricity. The point of the discussion on probabilities of low impact angles is to show that ellipsoidal impacts are expected, but they are a small percentage of impact craters. If the probabilities are low for ellipsoidal impacts, then the large numbers of such impacts discussed in this paper indicate larger numbers of circular impact craters yet to be found.

1.3 The nature of comets compared to asteroids

The main differences between asteroids and comets are the orbits, porosity, and size distribution. NASA have excellent photographs of Hyperion, a moon of Saturn that is highly porous and is probably a captured comet.

Comets typically are more ice than rock, but it is believed that some asteroids are comets that have out-gassed their water and the rocky part remains. For this paper, the main differences of interest are the orbits, low density and porosity. Many comets run highly eccentric orbits, with orbital periods in the dozens to thousands of years. As they approach the Sun they accelerate, reaching speeds of 60 to 75 km/sec as they pass Earth's orbit. Most asteroid and comet orbits lie in the ecliptic. Many comet orbits are far from the ecliptic plane but this paper is not able to identify impacts from such orbits and they are not of interest for this discussion. Most asteroids are small, with only about 200 of the millions observed larger than 100 km in diameter. Many comets are much larger than 100 km. The majority of short period (less than 200 years) comets are from the Kuiper Belt, and there are over 130,000 comets in the Kuiper Belt that are greater than 100 km in diameter (*Petit et al.,* 2011). Most objects/comets in the Kuiper Belt are on the Ecliptic +/- 5° (*Petit et al.,* 2011). Hyperion, one of Saturn's moons, is thought to be a captured comet and is 250 km in diameter. Eris, also in the Kuiper Belt and now classed as a dwarf planet, is 2000 km in diameter. So for discussion in this paper, "asteroid" refers to smaller objects generally of solid composition, of rocky or metallic material, traveling in similar orbits to the planets. "Comet" refers to objects largely made of porous ice, with some rocky and metallic materials mixed in, that travel in eccentric orbits, that pass or hit the Earth at high speeds of 60 to 75 km/sec, with many very large in size.

1.4 Comet Impacts are Different than Asteroid Impacts

Impacts from comets of low density, porous material, traveling at higher speeds will create different impact craters than solid more dense asteroids traveling at lower speeds. Schultz and *Gault* (1985) conducted studies on clustered arrays of impactors which produce significantly different craters than expected with single object impacts. However, the majority of studies on impact dynamics are based on the premise that impactors are well represented by a solid sphere of rock or metal. This is accurate for most asteroids. Asteroids usually hit as a single piece of rock, whereas comets can easily break up into many pieces before impact. These pieces can form clusters or trains of fragments which have different effects than single objects. Lower speed, solid objects will hit Earth explosively, always forming a spherical shockwave and will usually form a circular crater (*Elbeshausen et al.,* 2009). In comparison, with the speed of comets and their elongated shapes or dispersed natures, some will penetrate the Earth's crust instead of exploding, and some will skip, with both of these styles of impacts producing craters unlike asteroid explosive impacts.

Many studies of ballistic cratering have been done. The most meaningful are those run at speeds of 10

to 20 km/sec, matching the actual speed of asteroid impacts. The cratering processes are well understood, and the shock metamorphic effects well defined (*French and Koeberl,* 2010). However the planetary impact related literature has little reference to studies of irregular shape objects impacting (*Littlefield and Dawson,* 2006), and no studies of how impacts at very high speeds (over 25 km/sec) would behave if the Earth's crust was penetrated instead of exploding on impact at the surface.

1.4 Elongated Objects Produce Different Craters

Studies of impacts due to elongated porous comets are rare. One example is the recent thesis by *Potter* (2012) in which he reviewed porous oblate bodies, to determine survivability of impactors in craters. His conclusion is that increased length to width ratios increases survivability. This implies that depth of penetration also increases as expected from rod impact studies. A study by *O'Keefe and Ahrens* (1982) showed that porous and low density bodies react significantly differently than rocky or metallic bodies when they collide, producing a much smaller crater depth for a given diameter, and reducing the height of the rings and crater walls.

Studies have been done in other fields that relate to comet impacts. Bullets are extensively studied for military applications. They are elongated, and often tunnel into the objects they hit rather than exploding (*Gomez and Shukla,* 2001). Studies of long objects impacting solid objects, such as the work by *Orphal* (2006), show that the long objects tend to bore their way into the material as shown in Figure 2. Generally, the surface material is pushed ahead of the impactor rather than explosively tossed aside. If the object is long enough, then the edges of the deepening hole widen a bit around the impactor, and the leading material is jetted back along the edges of the impactor, typically at similar speeds to the speed

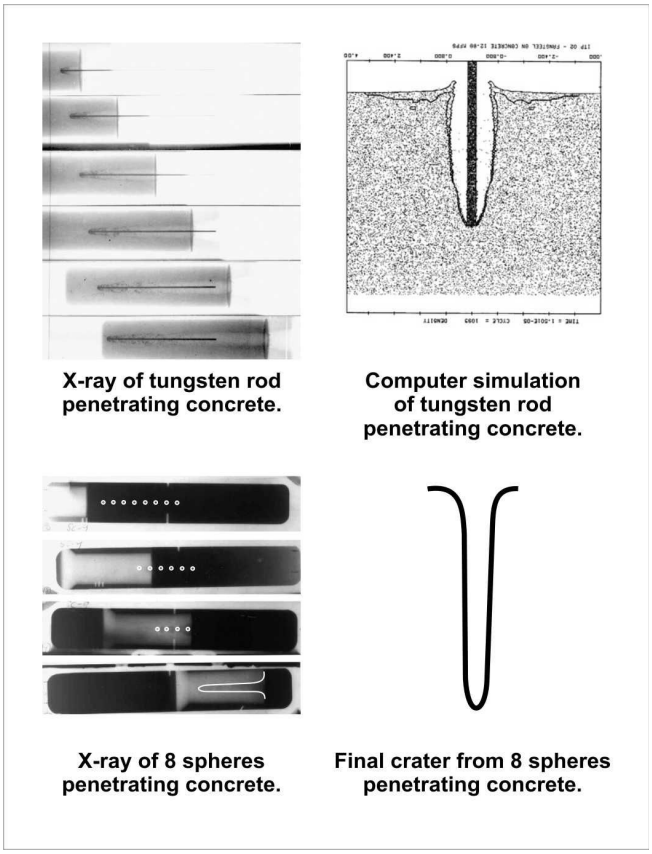

Figure 2: Examples of craters formed by Long Rods and trains of impactors.

of the impactor moving down. In many cases the impactor is tight in the hole with only a very tiny amount of blow back and little shock beyond a diameter of the impactor. A common example of such an effect is that nails can be driven into concrete by explosive charges, producing a deeper and stronger seal than one can achieve by hammering a nail into concrete.

1.5 Expected features of a comet impact crater

Figure 3 shows the process proposed for a large, penetrating impact of a non-spherical object. It is expected that when a comet hits, as an elongated comet or train of pieces, it will tunnel into the Earth, and a high speed ejecta will blow back in reverse direction to the comet's direction at speeds comparable to the comet's speed. Until the comet slows to below Earth's escape speed, the majority of the ejecta will be sent to space on a reverse

trajectory of the comet's original orbit. Little would return to Earth. As the impactor slows, the ejecta will slow and eventually some will fall back, but much less than with spherical impactors. This will lead to a significant problem in identification of comet impact craters: instead of the crust having received most of the shock and expressing shock metamorphic evidence from the explosion, the crust will be either push ahead of the comet deep into the mantle, or be blown away as ejecta. Neither will leave shock metamorphic evidence in the crust.

Eventually, the comet will stop deep in the mantle. The shock wave extending deep into the mantle will cause melting of the surrounding mantle. The melted mantle will rise part way back up the hole, and cool and form a thin layer of oceanic crust at the bottom of the crater. It is expected that the rapidly cooling oceanic crust that forms will have no faults, fissures, uplifts, or any signs of tectonic activity – there should be few earthquakes in the area for millions of years after. However, it is expected that the melted lithosphere will form hot spots that will eventually lead to volcanoes near the deeper end of the crater.

Some fall back will occur, filling the bottom of the hole with fine breccia. The breccia is expected to be formed of small pieces instead of the large blocks commonly found in an asteroid impact. A slower impact causes a shock wave forming a crater approximately ten times the diameter of the impacting object, that lifts the surrounding rock and drops it back into the crater, producing a large block breccia. A high speed penetrating impact produces either a crater up to ten times the diameter of the impacting object, or as little as the same size as the impactor. It depends on the length and width of the impactor. But with the high speed, what does not get ejected above escape velocity and does fall back into the crater has been shattered into small pieces. The fall-back breccia will be expected to be formed of small pieces,

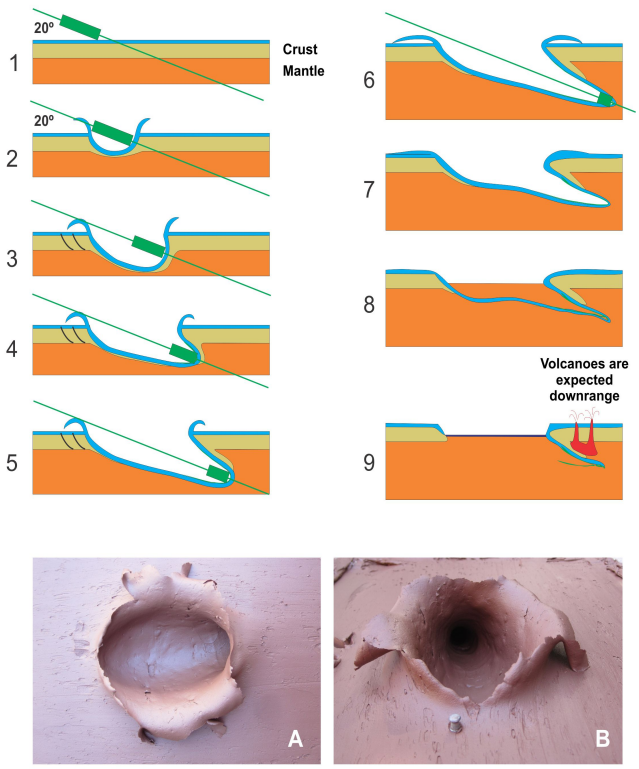

Figure 3: Expected behavior for a 20° impact by a long comet object, penetrating Earth's crust leaving a deep hole instead of a classic explosive crater. The drawings are estimations, based on impacts into clay. 20° impacts into wet clay with low speed pellets are shown in the bottom two photographs. Photo A shows that crater appears from above as an ellipse. The ejecta is tossed sideways. The pellet is shown in Photo B for scale. Photo B is the view along the trajectory. It has formed a cone with the point deep in the clay, but the surface expression is an ellipse.

which to a seismic survey will appear the same as simple ocean sediments. The rest of the crater will fill in with sediments and water, so it will become an ocean, sea or lake. The sea will be different than seas formed with Plate movement. It will be deeper, with steeper edges, and filled rapidly with sediments that will form thick horizontal layers.

1.6 The Hypothesis

It is hypothesized that some comet impacts will have formed ellipsoidal shapes with the long axis orientated at 23.4° relative to the Equator. These features should have the characteristics of

penetrating comet impacts as discussed above rather than standard Plate Tectonic features.

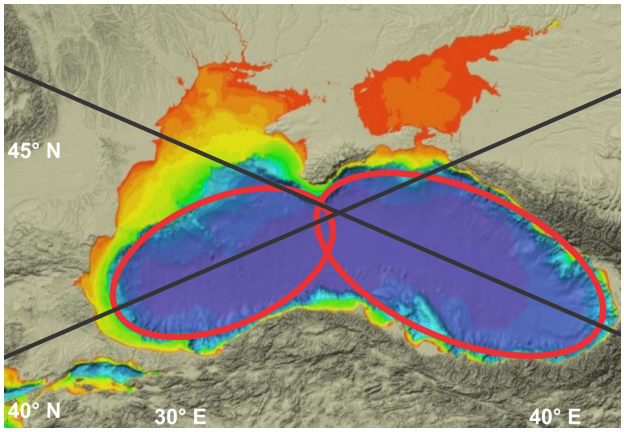

Figure 4: The Black Sea is well represented by two ellipses, tilted at 23.4° relative to the equator. Depth is color coded with purple very deep and red very shallow.

2.0 COMET IMPACTS ORIENTATED AT 23.4°

2.1 The Inexplicable Black Sea

The Black Sea is an excellent example of a 23.4° feature that is proposed to have been formed by comet impacts. The Sea is formed from two ellipses, each with the major axis tilted at 23.4° relative to the equator - one clockwise and the other counterclockwise. Figure 4 shows the two ellipses on the GEBCO bathymetric map. If this was the only feature on Earth with such a tilt, it would be of no significance, but there are others as will be shown later in this paper. The ellipsoidal shapes and tilt of the major axis are indicative of a impact origin, and there are many other features indicating that the Black Sea was formed by two impacts.

The geological cross section of the Black Sea, as seen in Figure 5, is unusual. The Sea is 16 km deep to the ocean crust, and it is presently filled with sediments in simple horizontal layers. The eastern basin is considered to be younger than the western basin by some such as *Spadini et al.,*

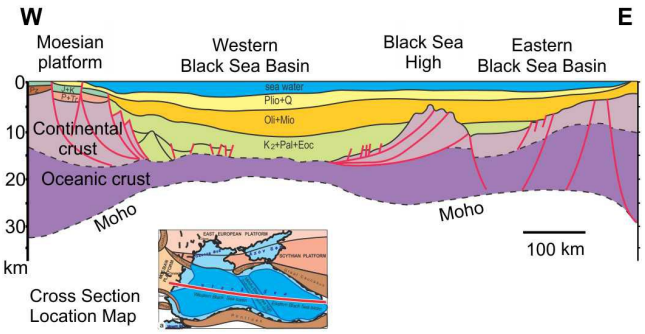

Figure 5: Geological cross section of the Black Sea.

(1996), and *Robinson et al.* (1995), and is shown as younger in the IGME 5000 maps. Others consider the two basins to be the same age (*Verzhbitsky and Lobkovsky,* 2002) – but note significant differences in the two basins' underlying lithology. In either case, the result is the same – the two basins are distinct geologically, which fits the interpretation that they were caused by two separate events. The ages of the layers are usually estimates based the depth of the sediments determined by seismics, or based on heat flow determinations (*Verzhbitsky and Lobkovsky,* 2002). The sediments are too deep to drill, so the ages can not be determined exactly – which is part of the challenge in determining how the basins formed. The edges of the sea are steep and the adjoining continental crust is heavily faulted and folded.

The Moho is very high under the Black Sea, and the crust is very thin (*Starostenko et al.* 2004). Average ocean depths are in the range of 4 to 6 km deep. The deepest part of the ocean is only 11 km deep in the Mariana Trench – where the ocean crust is being thrust below the continent. The depth to the crust in the Black Sea is 16 km which is much too deep to be a remnant of older sea floors, much deeper than any trench or continental rift, and there is no evidence of any crust being subducted.

The Black Sea is commonly described as a rapidly sinking depression that filled in with sediments as

it sank (*Nikishin et al.,* 2003). If it was a Tectonic depression, then the surface crust would have moved down with it, yet there are no remnants of surface rock types in the Black Sea other than as sedimentary fills. Such a downward movement from a sinking depression would still have earthquakes associated with its downward motion - and the edges would be moving into the center. Instead the edges are pushing outwards and the north and south coasts are compressing the crust around the Black Sea (*Tari et al.,* 2000; *Maden* 2013), and there is no evidence of downward motion in the Black Sea's crust.

Alternatively, the Black Sea is considered as an extensional feature (*Shillington et al.,* 2008). If it is an extensional feature, then the crust is being pulled apart - but that would lead to very different faulting in the crust than is present, and the edges of the Sea would be moving out from the Sea's center which GPS measurements do not show (*Tari et al.,* 2000 & *Turkish National Fundamental GPS Network* 2014). Extension of the crust would also lead to the center being younger than the edges, so there would be less sediments in the center than at the edges. The sediments are horizontal layers across the sea with no central thinning.

If the Black Sea was formed by rifting, there

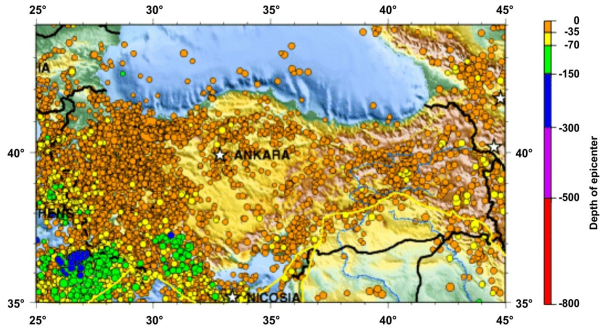

Figure 6: USGS map of earthquakes around the Black Sea, 1990 – 2006.

should be faults, earthquakes and volcanoes in it. There are many in the continental crust around the Black Sea, but none in the Black Sea itself, as shown in Figure 6.

Plate Tectonics is essentially recognized and defined by movement of the plates, which always cause earthquakes. Depressions, extensions, rifting or movement of any sort must have earthquakes. The earthquake pattern of Figure 6 shows that the land around the Black Sea is intensively active with abundant earthquakes, but there are few in the Black Sea, and it must be considered as tectonically stable and not active.

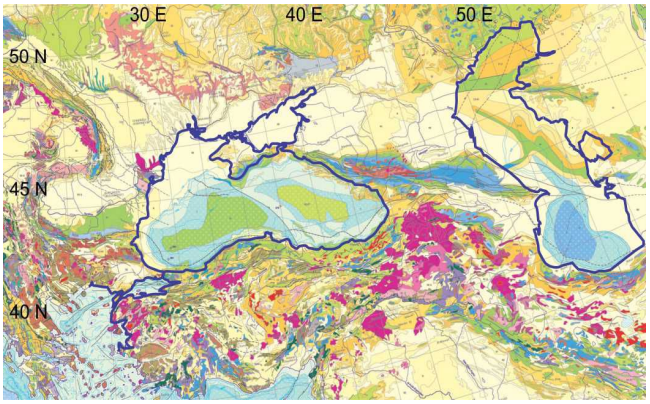

Figure 7: Geology around the Black Sea from IGME 5000*. Note the lack of any folding in the Black Sea or Caspian Sea - the thin oceanic crust is apparently stronger than the surrounding thick continental crust.*

A review of the geology of the area around the Black Sea as shown in Figure 7 shows that the continental crust is severely compressed and broken from the northward movement of Arabia and Africa, pushing into Europe, forming mountains, rifts, volcanoes, and generally folding and compressing the continent. The Black Sea is filled with layers of horizontal sediments, with no rifting, compression, mountains, volcanoes, or earthquakes.

At present it is explained that the very thin 4 km oceanic crust of the Black Sea has a strong lithosphere that is able to resist the forces of Arabia and Africa moving north (*McClusky et al.*,

2000), while the 30 - 45 km continental crust with a similar thickness of lithosphere is unable to resist it. *McClusky et al.* (2000) also propose a decoupling of the crust from the mantle to help explain the westward motion of the crust south of the Black Sea. It is mentioned that the pushing by the Arabian plate is not able to explain the westward motion.

(*Verzhbitsky and Lobkovsky*, 2002) use heat flow measurements to calculate the thickness of the lithosphere under the Black Sea, and conclude that the lithosphere is approximately 60-65 km thick under the Black Sea, and the lithosphere around it is thicker – ranging from 100 to 250 km thick to the north and west. They consider the effects of the thick sediment layers reducing the actual measured heat flows, and adjust the results to compensate for that. *Maden* (2103) reviews the lithospheric thickness based on heat flow measurements, and concludes that the lithosphere under the Eastern Black Sea is approximately 100 – 120 km thick, and the lithosphere to the south is much thinner at 50 – 60 km thick. However, *Maden* (2103) also concludes that the lithosphere just to the east of the Black Sea is over 200 km thick. If the thick, cold lithosphere under the Black Sea is pushing the thin lithosphere under the land to the south, then the much thicker lithosphere to the East should resist movement of the continent more than the Black Sea. The volcanic activity, earthquake activity, compressed crust, and mountain building to the East of the Black Sea indicate the the thicker lithosphere does not accomplish this. The Black Sea lithosphere should show more movement and compression than the twice as thick lithosphere to the east, but it shows none.

Reilinger at al. (2006) update the work by *McClusky et al.* (2000) and explain the plate motions around the Black Sea as primarily movement towards the subduction zones in the Hellenic and Cyprus trenches, with the lithosphere formed of several strong blocks that seem to be moving independently and not deforming. They conclude that Arabia is not the main driving force in the movement of the crust in Turkey. But they also recognize that the understanding of the motions is challenging and needs more study to clarify it.

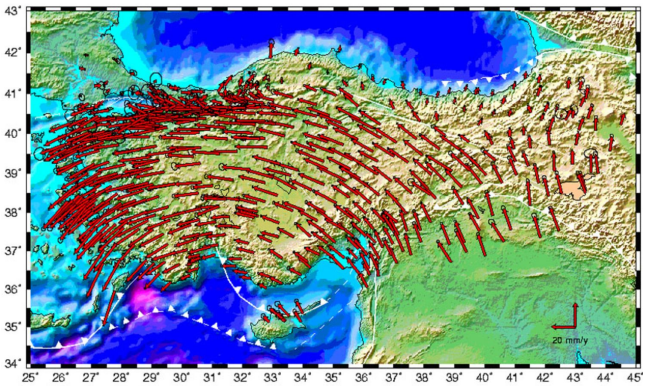

Figure 8: GPS measured motion of surface land in Turkey. Arrows indicate direction of movement. Length of arrow is relative to speed.

Present GPS technology has enabled geologists to measure the Earth's actual continental movement. In general GPS measurements show that Africa, Arabia and Europe are all moving northeast at relatively similar speeds (*NASA JPL* 2014). Detailed measurements by the Geological Survey of Turkey (*Turkish General Command of Mapping,* 2014) show a different picture of the local movement around the Black Sea as shown in Figure 8.

The surface movement in Turkey shows that the continental crust is being pushed away from the Sea, and the western section is moving in the opposite direction to the general movement of Europe. Assuming that plate movements are driven by the mantle underneath the continents, then the mantle under Turkey must be moving northeast. It is impossible to explain backwards motion in a small part of the lithosphere with traditional Plate Tectonics. *Reilinger at al.* (2006) suggesting decoupling of the crust and mantle is

necessary to explain the backwards motion – but standard Plate Tectonics theory would not allow it. However, an impact would deliver energy and momentum to the lithosphere it hits, and the lithosphere would continue to move from the impact for a long time – even if it is against the direction of mantle flow.

2.2 Examples of the challenges in describing the origins of the Black Sea.

The present geological theories on the formation and origins of the Black Sea do not provide satisfactory explanations. Some samples of the debate on the Black Sea's formation show the extreme difficulty explaining its origins:

"The present-day tectonics of the Black Sea has been a puzzle. … The origin of the Black Sea has been long studied and is complicated in detail." (*Tari et al.,* 2000)

"There is a speculation that the lithosphere of the Black Sea and Caspian Seas form a resistant "backstop" diverting the impinging Anatolian plate to the west and "funneling" the continental lithosphere of eastern Turkey and the Caucasus around the eastern side of the Black Sea." (*McClusky et al.,* 2000)

The Black Sea and Caspian basins "are remnants of a much greater marginal sea formed during three separate episodes during the Mesozoic: in the Middle Jurassic, Upper Jurassic and Late Cretaceous." (*Zonenshain and Le Pichon,* 1986)

"Seismic data show that the eastern Black Sea has evolved via a sequence of interrelated tectonic events that began with early Tertiary rifting followed by several phases of compression, mainly confined to the edges of the basin. ... It is also suggested that extension of a 40–45 km thick pre-rift crust is required to generate the observed magnitude of total subsidence." (*Meredith & Egan,* 2002)

"Subsidence analysis of the eastern Black Sea basin suggests that the stratigraphy of this deep, extensional basin can be explained by a predominantly pure-shear stretching history. … The timing of opening of the eastern Black Sea, which occupied a back-arc position during the closure of the Tethys Ocean, has also been a subject of intense debate; competing theories called for basin opening during the Jurassic, Cretaceous or Paleocene/Eocene." (*Shillington et al.,* 2008)

There is clearly no consensus about the formation of the Black Sea. It is not clear if it is a depression, extension, rifting, remnant of an older sea, or something else. It is not clear how old the Black Sea basin is. But it is clear that the Black Sea is different than most seas or oceans. An impact origin would resolve the challenges and provide a simple explanation of how the Black Sea formed.

2.3 The Caspian Sea South basin

If the Black Sea was unique, then one could accept that studies of Plate Tectonics will eventually explain how it occurred and an impact origin could be easily dismissed. However, there are other basins with similar features. The Caspian Sea's southern basin also fits an ellipse with a major axis at 23.4°. Its geology and features are essentially the same as the Black Sea's (*Zonenshain and Le Pichon,* 1986). Figure 7's geological map shows the crust surrounding the Caspian Sea is similar to what surrounds the Black Sea, and the above notes on the difficulties explaining the Black Sea apply to the Caspian Sea.

2.4 The Tarim Basin Features Match the Black Sea

A larger 23.4° ellipsoidal feature on Earth is the Tarim Basin as seen in Figure 9. It is a flat desert 700 km across, in the middle of the world's highest mountains. It is understood that the Himalayas are a result of India moving northward

colliding with Asia (*Yuan et al.,* 2013) and the edges of the continents have rippled and compressed forming the mountains. But as with the Black Sea, the Tarim Basin has not been effected by the mountain building around it. It has deep horizontal layers of sediments overlying a thin crust, with minimal faulting and no earthquakes. The crust is only 40 km thick in the

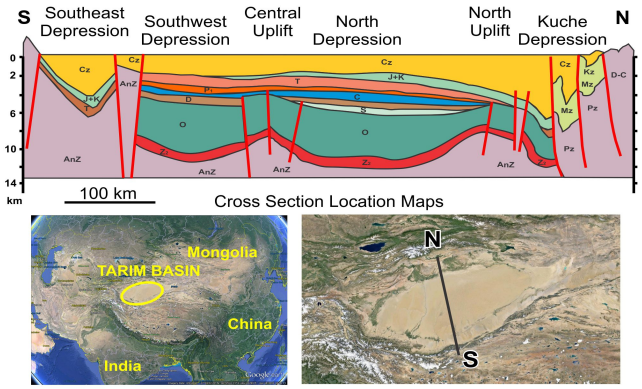

Figure 9: Geological cross section of Tarim Basin - some compression is effecting it but it is still primarily horizontal layers of sediments filling a vast hole.

Tarim Basin, but is 60-80 km thick in the surrounding area (*Zhang et al.,* 2011).

Figure 9 shows the Tarim Basin geological cross section (*Zhang et al,* 2007). The Tarim Basin is not filled with simple horizontal layers of sediments as with the Black Sea. They are essentially horizontal, but compression from India's movement north has begun to affect the Tarim Basin giving it some minimal faulting and compression. However, all of the main features found in the Black Sea are present here. The GPS measurements shown in Figure 10 (*Gan et al,* 2007) indicate that the Tarim Basin is pushing out on the Himalayas, rather than the Himalayas compressing the Tarim. It has a small northward movement while the rest of the Himalayas have a strong north east to east movement. The crustal movements have been diverted to the east against the mantle flow to the northeast.

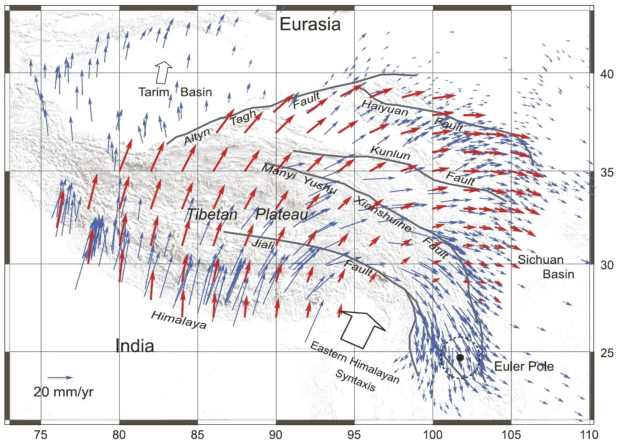

Figure 10: GPS Measurements in China show that the Tarim is pushing eastwards on the Himalayas.

The Tarim Basin is compressing the lithosphere around it, rather than the plates compressing the Tarim Basin (*Wittlinger et al.,* 2004). Figure 11 is a map of faults zones in the Himalayas. It shows that the Tarim Basin area is stable and has no major faults while the surrounding areas are extensively faulted (*Gao et al.,* 2011).

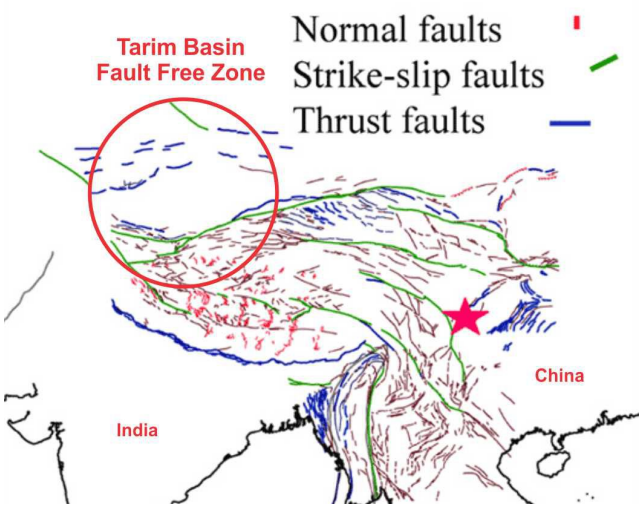

Figure 11: Geological map of faults in India and China. Tarim is a fault free zone.

The Tarim Basin is also an earthquake free zone like the Black Sea, as shown in Figure 12. This shows that it is tectonically stable and it could not have been formed by tectonic activities.

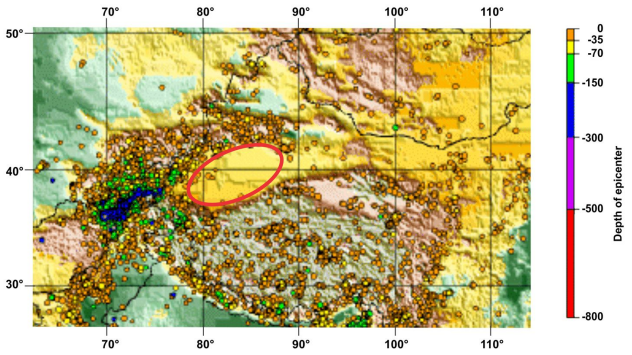

Figure 12: USGS earthquake map of Asia 1990 – 2000.

Features in common with the Black Sea, the south Caspian Sea and the Tarim Basin are:

- 23.4° orientation,
- deep horizontal layers of sediments filling excessively deep holes in the crust,
- thin crust with a high Moho under them,
- minimal earthquakes,
- minimal faults, but surrounded by areas excessively compressed and faulted,
- outward compression on the surrounding lithosphere and crust,
- unusual history that is difficult or impossible to explain with Plate Tectonics.

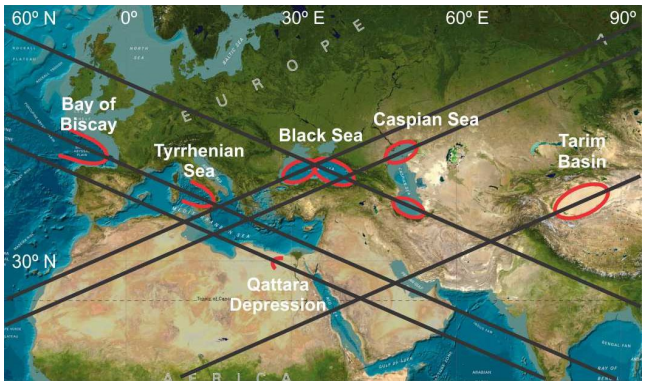

Figure 13: 23.4° features in Europe and Asia.

2.5 Other 23.4° Features on Earth

There are many other areas on Earth that fit these features. Figure 13 highlights some in Europe and Asia. Figure 14 shows Lakes Ontario and Erie with the 23.4° features highlighted. There is some distortion in the Great Lakes due to recent sedimentation, but the 23.4° features are clear. While some of these features are deep impacts, others such as the Northern Caspian Sea, Lake Erie, and Lake Ontario are proposed to have been skips with comparatively shallow depths. The Great Lakes are generally believed to have been formed through erosion by glaciers (*Karrow and Occhietti* 1989), but the flow of the glaciers was mainly to the south and the lakes are orientated east-west. The sediments removed from the Great Lakes' basins needs to have been moved somewhere, but they are not accounted for. The drumlins and moraines around the lakes are not sufficient to account for the vast amounts of materials removed from the lake basins. Impacts would have tossed the sediments far away – mainly into space.

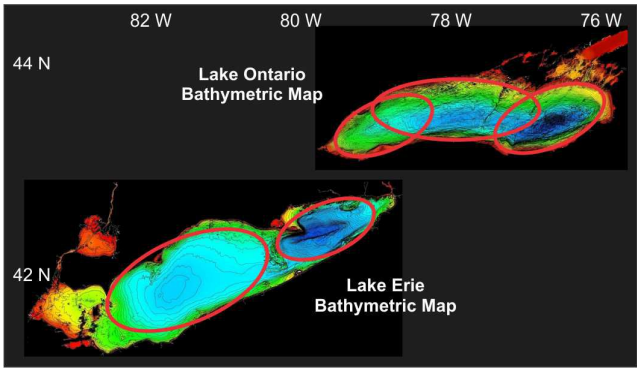

Figure 14: Lake Erie and Lake Ontario bathymetric maps with 23.4° degree ellipses highlighted. Lake Ontario has a third ellipse of near horizontal orientation in the middle.

The Bay of Biscay and the Tyrrhenian Sea are examples of proposed impacts into the edge of a continent producing a crater of only half of an ellipse. The Qattara Depression in Egypt is also half of an ellipse, with a gentle slope rising to the south east from the depression. It may be a case in which the comet hit and shattered and spread out to form the final impact area.

All of these features are earthquake free, and all are close to 23.4° in orientation of the long axis. To go over each one in detail in a short article is not appropriate. However, they all have similar features and the Black Sea and Tarim Basin are excellent examples of them.

Impacts can explain all of the unusual features of these lakes, seas and basins. Plate Tectonics and glaciation can not.

2.6 The Hoba Meteorite Enigma Explained

A good theory should be able to predict solutions to inexplicable cases. Allowing for massive impacts and skips solves the mystery of the Hoba meteorite. The Hoba is the world's largest meteorite at 66 tonnes. It was found in Namibia just a few centimeters below the surface by a farmer plowing his fields. It is estimated to have fallen in the last 80,000 years based on the radiometric dating of ^{59}Ni, a spallation product nuclide (*McCorkell* 1968).

According to the Earth Impact Effects Program (*Marcus et al.* 2010), if it fell at the lowest possible impact speed of a meteoroid at 11.2 km/sec, it would have formed a crater of 80 to 100 meters diameter, and be buried 20 meters deep. At present it is postulated that atmospheric ablation allowed it to slow enough to land gently. *Beech* (2013) analyzes the concept in detail and shows that it is conceivable to have a flat meteorite entering the upper atmosphere at a low angle of less than 16° that can ablate and slow to less than 200 m/s allowing for a gentle landing. However, his formula for atmospheric density is not accurate. From 200 km to 100 km his densities are up to 7 times too high, slowing the meteor much too soon and too fast. For altitudes less than 20 km it gives density values up to 50% higher than actual, allowing the final gentle landing.

Beech (2103) mentions a second alternative that his paper does not focus on. He notes that the Hoba Meteorite is a single piece. To have not broken on impact requires that either it must have come from a single parent body that ablated and landed slowly or the shock of impact would have shattered it; or that it was part of a larger body that did shatter on impact, and the Hoba is only a portion of the original body. There is no crater around the Hoba, not even the 5 meter depth *Beech* (2013) calculates for a gentle landing. The land shows minimal erosion, so the erosion of 4 meters of surface in 80,000 years is unlikely. For the Hoba meteorite to be found on the surface with

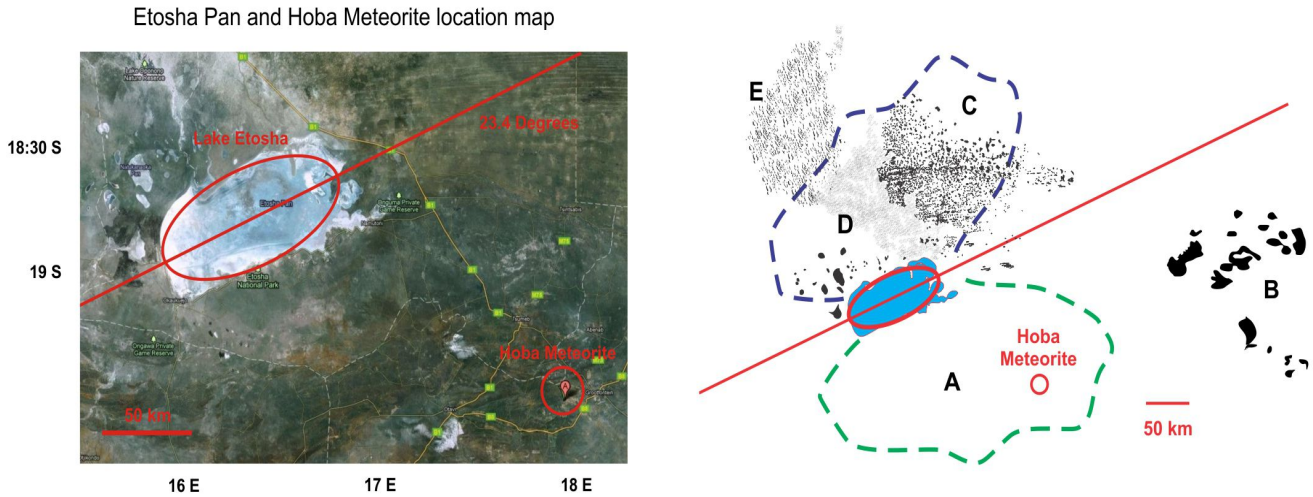

Figure 15: Etosha Pan and Hoba Meteorite. The Splash Pattern around Etosha Pan is typical of impact ejecta patterns.

no crater shows that it must have landed with the main vector in a horizontal direction. Therefore, it must have been part of a larger body that did shatter on impact, and was tossed sideways.

A comet hitting Earth at a very low angle would skip. Skipping would cause it to shatter, and although most of the debris would travel away from Earth and into space, some of the comet and impacted land would be tossed sideways in a shower of debris. The Debris would have both vertical and horizontal motion, but it would be mainly horizontal.

If this happened, the impact crater should be near. It would be convenient if it was at 23.4° to clearly fit this theory. Such a feature exists in the near vicinity of the Hoba. It is Etosha Pan - a shallow lake that is 150 km long, and fits a 23.4° ellipsoid as shown in Figure 15. It is very similar in shape and depth to the south part of Lake Erie and the north part of the Caspian Sea.

As with the Black Sea it is difficult to explain how it formed. It is proposed to be a wind erosion effect (*Miller et al.,* 2010), but the prevailing winds are due east, not at 23.4°. It is largely filled in with sediments and clay, and is presently very shallow.

Figure 15 shows depressions around Etosha Pan. Etosha lies near a border between surface exposed bedrock to the south and soft soil and gravel to the north. The bedrock to the south has a dark green discoloration, which is outlined with the green dashed line. The Hoba meteorite was found in this zone. To the north the land is covered with depressions highlighted in black. They range in size from meters across in areas E and D to kilometers across in area C. The depressions in Area E are stretched to the north by water erosion - a wide, shallow river runs through the area. These depressions may be simply river erosion features. The depressions in Areas C and D are much larger and are used for farming and as locations of small villages. The soil in the depressions is good for agriculture but the land around the depressions is too rocky. The blue dashed line is a reflection of the green dashed line. It encompasses most of the larger depressions in the north. Area B has a few very large but shallow depressions. Allowing for differences in land surface types in the area, the pattern is a typical butterfly splash pattern. It would be interesting to run a magnetometer around the splash areas to the north of Etosha to confirm the presence of metallic meteorites in some of them. It would be a simple proof of the impact origin theory.

3.0 DISCUSSION

3.1 The problem of size and lack of proof.

The only theory available at present to explain Earth's features is Plate Tectonics, so it is assumed that everything can be explained with it. But some features do not have reasonable Plate Tectonic explanations. Although many mechanisms have been proposed, the origins of the Black Sea remain highly debatable. With 16 km depths, they can not have originated as standard oceans, and with no tectonic activity they stand out among the mountains around them as dramatically different. The Tarim Basin does not fit the Indian Plate moving northward forming the Himalayan mountains while leaving the Tarim flat and unaltered. The Great Lakes are assumed to be glacial features without an adequate explanation of where the missing sediments are or how east-west oriented lakes were carved by southward moving glaciers. Hypothesizing impact origins provides an alternative explanation that explains the geology and orientations of these features.

A challenge of this hypothesis is that the size of the craters is larger than presently acceptable. At present, Vredefort is the largest accepted crater, and it is less than 300 km in diameter (*Spray* 2015). These proposed craters range from 300 km

to 1000 km in length. Size being a problem is largely a historical viewpoint. Craters were only accepted as possible in 1963 when Eugene Shoemaker proved that the Barringer Crater in Arizona was not a volcanic feature but was an impact crater (*Shoemaker,* 1963). In the past 50 years craters have been accepted on most planets, but are still not readily accepted on Earth unless they are "proven" with similar shock metamorphic evidence as was shown in the Barringer Crater. While the criteria for proof of an impact are well defined (*French & Koeberl,* 2010), they are specific for asteroid impacts and they exclude low angle, higher speed comet impacts.

Low angle impacts of 15° or less are recognized to vaporize nearly 100 times the mass of the impacting material compared to a vertical impact which vaporizes little (*Schultz,* 1987). The vast majority of recognized impact craters are due to higher angle impacts forming circular craters. With little surface rock vaporized in such circular craters, shock metamorphic signatures are expected. But with 100 times the mass of the impactor vaporized in a low angle impact, there is no surface material remaining to show the shock metamorphic evidence in these craters.

At present, all recognized craters are due to asteroids and none are recognized from a comet impact (*Spray* 2015). As discussed above, comet impacts will be significantly different. The question to be asked is: can we accept a crater on Earth on the criteria we use for other planets, basing the acceptance on shape and geology, not on asteroid impact style shock metamorphic proof? Less than 200 craters in the solar system have shock metamorphic proof but millions of craters have been recognized on Mars, Mercury, the Moon, asteroids, comets and virtually every orbiting body in the solar system, all based on evidence other than Shock Metamorphism. To limit our recognition of impacts on Earth to those with shock metamorphic proof is not justified.

3.2 The problem of missing boundary layers

If we accept that these features are impacts, then there is the problem of the extinction events and boundary layers to be expected. Chicxulub is one of the largest craters presently recognized on Earth. It is associated with the world wide K/T boundary layer that defines the impact that wiped out 95% of all living creatures on Earth, 65 million years ago (*Schulte et al.,* 2010). The K/T boundary layer fits Chicxulub well, and no other crater is recognized that would fit the K/T boundary layer. However, Chicxulub is only 180 km in diameter. If Etosha Pan, the Black Sea, Tarim Basin and others are impacts, and they are much larger than Chicxulub, then there should be boundary layers and extinction events associated with them. There are no accepted worldwide boundary layers to correlate to their impacts, and although there are many unexplained extinction events, none are specifically associated with the Black Sea, Caspian Sea, or the Tarim Basin. However, considering that the ages of these suggested impact craters have not yet been determined, it is probable that there are associated extinction events that will correlate with the ages of these impacts.

Furthermore, when a comet hits at 60-75 km/sec, the vast majority of the comet material will either be buried deep into the Earth or ejected at speeds in excess of the escape velocity, and be lost to space. *Alvarez* (1980) predicted that nearly ¼ of an asteroid would remain as dust in the atmosphere after an impact, enabling it to form a world wide boundary layer. The rest of the asteroid would be mixed in the ejecta and fall back material. For a comet impact, very little of the comet would remain to be identified in a boundary layer.

Jeffers et al. (2001) showed that the deposits by a higher speed comet are dramatically less than from a lower speed asteroid:

"In fact, provided that the body is in the multi-kilometre size range, the fraction of the mass of the impactor deposited is a sharply decreasing function of the impactor velocity. … above 25 km/sec essentially none of the impactor mass is retained. This means that the initial mass required to explain any given Iridium anomaly increases rapidly with increasing impact velocity above 20 km/sec."

Therefore, it is expected that a comet impact will leave little or no boundary layer, or if there is a boundary layer, it will be very minimal. The boundary layer for the proposed Younger-Dryas impact event is minimal (*Bunch et. al.,* 2012), and fits what is expected for a comet impact such as the ones that are proposed to have formed Lake Erie and Lake Ontario.

One aspect of the hypothesis of this paper is the prediction that impacts are an on-going process that has covered the planet with as of yet unidentified craters. Most are filled with water, and classed as lakes or seas. Many are under the oceans and not visible, or are full of sediments and not noticed. This paper can not show detailed evidence for thousands of craters. Instead it focuses on one small group of elliptical craters, caused by low angle impacts from high speed comets. Acceptance of these as impacts implies that many other comet impact craters exist, and that the size of craters on Earth includes many much larger than presently accepted.

3.3 Considerations on 23.4°

While 23.4° is the present tilt of the Earth, it varies by about 2° with time, so ancient impacts may be off by 2° or more depending on the age of the impact. Plate Tectonics rotates continents with time, so some craters originally at 23.4° will now be at different angles.

The usage of 23.4° in this presentation is not meant to be an exact number, but a representative number that is close enough to the reality to be significant. Not all ellipses are perfect alignments with the axis, but all are close enough to justify the recognition of events related to impacts from bodies in the Ecliptic rather than to Plate Tectonic activities. As previously discussed, it should be noted that the 23.4° angle is a maximum. The direction of travel can be anything from the maximum to zero with respect to the Equator, depending on where and when it impacts the Earth. There are many impact like features with angles different than 23.4°, but they are not uniquely determined by their angle as comet impacts so they are not part of this discussion. The 23.4° features make a small percentage of the impact craters on Earth, but they are unique in that they can only have been caused by impacts, and their orientation allows them to be identified more easily.

3.4 Are Meteor Showers indications of recent comet impacts?

Meteor showers are generally thought to be from the out-gassing and loss of pieces as a comet orbits the Sun. Recent satellite approaches of comets Hayabusa and Rosetta do not show such streams of debris associated with them. We know that the annual meteor showers follow the orbits of specific comets. If debris trails are not standard with comets, how do they form? Perhaps they are after-effects of impacts. When a comet impacts, especially for one that skips rather than hitting straight on, a stream of ejecta will go into orbit about the Sun. The debris will be in a reverse direction to the original comet for a non skip and in the same direction for a skip. The debris from the ejecta will be sent off Earth at a similar speed to the original comet. It will have enough range of speeds to allow the ejecta to become an extensive train of particles extending for vast distances. Since the original comet was on an Earth crossing orbit, the train of particles will also be on the same Earth crossing orbit. The debris must slowly be captured by the sun and planets - which leads to

the conclusion that meteor showers imply recent impacts on Earth. Whether "recent" implies thousands or millions of years will require further study.

SUMMARY

Many features on Earth fit impact origins better than they fit Plate Tectonic origins. Finding many ellipsoidal features with long axis at 23.4° is surprising, but they exist and Plate Tectonics can not be effected by the tilt of the Earth, nor can it randomly produce so many 23.4° features. Plate Tectonics can not explain why these features are in stable, earthquake free zones. Many lakes, seas and ocean features are well described if they are impacts, but difficult or impossible to explain as Plate Tectonic features. If there are so many massive ellipsoidal impact craters with 23.4° long axis, then there must be hundreds or thousands more of similar size with other orientations and of circular shapes.

Features on Earth that can be explained by massive impacts:

- The shape of the Black Sea, South Caspian Sea and Tarim Basin.
- The presence of thick layers of undisturbed horizontal sediments in areas that should be compressed by plate motions.
- The thin oceanic crusts and high Moho.
- The localized absence of earthquakes in otherwise highly active areas such as Turkey and the Himalayas.
- The outward pressure of Tarim, the Black Sea, and the Caspian Sea on the mountains around them.
- The backward movement of the crust in Turkey compared to the mantle flow.
- The sideways movement of the crust in China compared to the mantle flow.
- The Hoba Meteorite's origin.
- Many other 23.4° ellipsoidal features' origins including Lake Ontario and Lake Erie.

The present criteria for proving that a feature is a crater is too narrow and excludes many craters from being recognized. The criteria on Earth should be changed to allow for features that fit the criteria we use on the other planets and moons. Shape, location, orientation, depth, size, and implausibility of Plate Tectonic explanations should all be considered as significant determining factors. The presence of shock metamorphic features should not be the determining factor. Creating a unique set of rules on Earth that only defines a crater as an impact if one finds shock metamorphic evidence is not justified since the vast majority of accepted craters in the solar system have no shock metamorphic evidence.

CONCLUSIONS

The Black Sea, South Caspian Sea, and the Tarim Basin are impossible to explain through present Plate Tectonic interpretations. Instead, their features have the characteristics of penetrating comet impacts. Lake Erie, Lake Ontario and Etosha Pan match what is expected for a skip impact. Their 23.4° orientation relative to the Equator highlights their impact nature.

Earth has many features that fit the characteristics of massive impact craters, but they are not presently accepted. Some orientated at 23.4° have many common features with the Black Sea, South Caspian Sea and the Tarim Basin, implying that they are of similar origins, and are probably impacts.

Noting that some 23.4° features are likely to be comet impact features, and that the Etosha Pan fits that criteria, proposing that the Hoba is part of a comet skip impact provides a realistic solution to the enigma of the Hoba meteorite.

Plate Tectonics plus frequent massive impacts explains many of the features not explained by Plate Tectonics alone.

It is apparent that impact events are much larger and more frequent than presently accepted. Should this be accepted as a valid theory, it will profoundly influence the understanding Earth's history and that of the entire solar system.

FIGURE CREDITS

Figure 1: Google Earth image of the planet with annotations by the author.

Figure 2: *Orphal,* 2006

Figure 3: Drawings and photos by John Burgener.

Figure 4: Black Sea Image reproduced from the GEBCO (General Bathymetric Chart of the Oceans) world map 2010, www.gebco.net, http://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_08_update_history/version_20100927/

Figure 5: *Georgiev,* 2012

Figure 6: USGS - Seismicity of Turkey, 1990 – 2006

Figure 7: *Asch, K.* (2005): IGME 5000

Figure 8: Turkish National Fundamental GPS Network, www.hgk.msb.gov.tr/english/u-10-turkish-national-fundamental-gps-network.html

Figure 9: *Zhang et al,* 2007

Figure 10: *Gan et al,* 2007

Figure 11: Caltech Tectonics Observatory www.tectonics.caltech.edu/outreach/highlights/2008MayChinaEQ/

Figure 12: USGS map of earthquakes in Asia, 1990 -2000

Figure 13: 23.4° features in Europe and Asia, overlaid on the Mercantor projection map from The General Bathymetric Chart of the Oceans (GEBCO), www.gebco.net/data_and_products/gebco_world_map/images/gda_world_map_large.jpg

Figure 14: Bathymetric maps of Lakes Erie and Ontario from the National Geophysical Data Center NOAA, www.ngdc.noaa.gov/mgg/greatlakes/

Figure 15: Etosha Pan and Hoba Meteorite highlighted on Google Earth image. Splash Pattern around Etosha Pan drawn by John Burgener based on Google Earth information.

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