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Cratering and the Earth: Clues in Lineaments

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Abstract

Lineaments are a well-recognized landform. They have been connected with basement shear zones that affect topography. Using satellite mapping, I examine circular lineaments, which show defined centers and concentric expressions at the surface. They are expressed geomorphically in both raised and lowered zones of elevation. Symmetry, repetition, and regularity can be used to discriminate lineaments from random features. Circular lineaments at Unaweep Canyon and the TONCK Structure are mirrored by topographic and gravity anomalies that display the physics of shock and release waves produced by impacts. It is possible that these features were produced by impacts, and that this hypothesis may allow a better interpretation of landforms.

Note from the Editor:
This paper is sure to be controversial. The author brings up some important issues, such as impacts and lineaments. I encourage further discussion on the topics the author raises.

Introduction

With the first release of satellite images to research institutions in 1972, the NASA symposium of 1973 had a majority of the papers centered on lineaments (Short, 1973). In 1977, Norman and Chukwu-Ike published "The World Is a Bit Cracked," recognizing large circular lineament in Africa and South America. Saul (1978) published "Circular Structures of Large Scale and Great Age at the Earth's Surface," concerning circular lineaments in Arizona. Byler (1983) presented a paper, "Circular Structures of Earth," concerning over a hundred circular lineaments he had mapped over North America. Burgener (2013) published "Massive Impact Craters and Basins on Earth: Regarding the Amazon as a 3500 km Multi Ring Impact Basin."

Daubree (1879) noted sections of coastlines that were parallel or concentric across the Atlantic. Similar patterns were mapped worldwide by De Kalb (1990). Lapworth (1892) mapped parallel elements in the dendritic paths of European rivers, as did Twidale (2004) in Australia. Hobbs (1904, 1911) noted significant patterns of lines on Earth's surface, and in 1911 first used the term "lineaments" to label these forms.

During the years before and in between, published maps of various specific areas were filled with traced lines of linears—short lineaments—traced from topographic features or gravity anomalies that show no clear pattern at a small scale but often show discernable straight or curvilinear patterns at larger scales. Lineaments are now such a part of geology that Gay (2012, p. 3) stated, "To not attempt to understand lineaments is to ignore one of the most common and basic features in geology."

Gay (2012) shows a direct relationship between mapped linears and lineaments in the Paradox Basin of Utah and the mapped crest of the Comb Monocline, which steps from one linear to another. He quoted Kelly and Clinton, field geologists with the USGS, who stated that the monocline exhibited "straight line segments with corners" that matched crossings of the linears, and then concluded: "On cratons, joints, linears and lineaments, as well as fractures and faults, result from reactivation of pre-existing faults/shear zones in the underlying Precambrian

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basement" (Gay, 2012, pp. 6, 10), a conclusion supported by Kreis and Kent (2000) and Penner and Cosford (2006).

A *lineament* is a mappable "simple or composite feature of a surface, the parts of which are aligned in a rectilinear or slightly curvilinear relationship, and which differs distinctly from the pattern of adjacent features and presumably reflects a subsurface phenomenon" (O'Leary and Friedman, 1978, quoted in Tiren, 2010). This definition was derived in the context of satellite imagery. Interpretation begins with recognition of short segments, called linears, each tracing a single topographic element. Linears stand out by contrast with the surrounding patterns. Geologists believe that lineaments reflect deep structural and tectonic features, and this is often validated by comparison with gravity and magnetic maps. Two types are described: rectilinear and *slightly* curvilinear (O'Leary and Friedman, 1978, quoted in Tiren, 2010). Lineaments inferred from *strongly* curvilinear elements form arcs or even circular patterns, depending on the scale used. This paper will focus on the recognition of *strongly* curvilinear lineaments, typically at a regional scale.

Scale and perspective are crucial to interpreting lineaments from satellite imagery. Inferred lineaments must be seen at various scales, and patterns are clarified by zooming in or out. Details of linears require closer views; gross features require more distance. An interpreter must take all the information, comprehend it at each level, and incorporate it with a regional picture (Appendix). It is possible that some features will be understood only at a global scale.

Impact Features: Earth vs. Celestial Bodies

Recognizing large-scale features depends on the height of the view and the portion of Earth's surface seen. Additional perspective can now be gained from our solar system. Other rocky bodies, such as the Moon, Mars, and Venus, show very high concentrations of surface impacts relative to Earth. Osinski and Pierazzo (2013, p. 1) note, "Meteor impact structures are one of the most common geological land forms on all the rocky terrestrial planets, except Earth." Less than 200 impact craters have been confirmed by the Earth Impact Database (2016). Part of this is attributed to soil and vegetation cover, erosion, and sedimentation, but the *recognition of lineaments can help find many of these.*

Finding patterns in Earth's landscapes has long been the goal of many, despite the lack of clarity. We are like Galileo (2004), who mapped the Moon's surface, observing mountains surrounding circular forms. He called them "protuberances and hollows" (p. 8a) or "prominences and depressions" (p. 9b) or "summits and cavities" (p. 10b). He compared them to Earth's valleys and mountains, but recognized the unique circularity of Moon's "cavities," "perfectly round and circular, as sharply defined as if marked out with a pair of compasses" (p. 12b) and later assigned them the name "crater," for the larger Greek cuplike bowl, a krater.

Many authors (Table I) have traced curved linears that combine to suggest circular lineaments; some extend to complete circles. This paper will do the same for two examples and argue that they are the result of impacts.

History of Lineament Studies

John Tuzo Wilson (1962), an early advocate of plate tectonics, saw two basic orientations of mountains. The first was circum-Pacific, extending from the extreme southern tip of South America through North America in an arc through Alaska, Siberia, Mongo-

Year	Author	Location
1973	Gintov	Ukraine
1977	Ramberg et al	Norway
1977	Norman and Chukwu-Ike	Africa, South America
1977	Norman et al	World Wide
1977	Van de Graaff et al	Australia
1978	Glukhovskiy	Siberia
1978	Saul	United States
1979	Eggers	New Zealand
1981	Moralev and Glukovskiy	Baltic and Siberia
1984	Witschard	Australia
1987	Byler	United States
1998	Kutina	South Africa
2004	Twidale	Australia
2011	Papadaki et al.	Crete, Greece
2013	Seleem	Sinai, Egypt

Table I. A date-ordered list of papers suggesting a significance to straight (megashears) and circular (craters) lineaments. Assembled largely from Twidale (2007) with many additions.

lia, China, and Indonesia. The other ran roughly concentric to the equator through southern Europe, south of the Black Sea, north of the Persian Gulf and India, through Indochina, and into Indonesia. Though linear on a global scale, Wilson saw that they were composed of arcuate segments. Neither of those trends corresponded with megashears, yet they showed the reality of small-circle and arcuate lineaments. Wilson also observed that "many young mountain ranges and island chains are arcuate in plan and that the dominate sense of over thrusting or structural vergence is in the convex direction of the arc" (Hoffman 2014, p. 201). This influenced his tectonic views of colliding fore arcs or island arcs (DeCourten, 2015).

A major problem with lineaments has always been the human factor; some individuals can see the patterns, even using them to find ore deposits or other economic minerals, yet other scientists cannot. Saul, a proponent of circular lineaments being craters, related a lecture where a well-known scientist told him: "It was fascinating, absolutely fascinating, wonderful stuff… *of course it can't be true*" (Saul, 2015, p. 59).

Others disagree (Burgener, 2013; Norman et al. 1977; Saul, 2015) but explain them primarily in the context of plate tectonics (e.g., Burgener, 2013; Byler, 1987; Neev et al. 1982; Norman and Chukwu-Ike, 1977). If any of these features are impacts, we should find craters at the centers of these features. Saul (2015) and Norman and Chukwu-Ike (1977) both suggested that the paucity of obvious craters is caused by collision and overthrusting. However, understanding geological expression depends on knowing the mechanics of cratering.

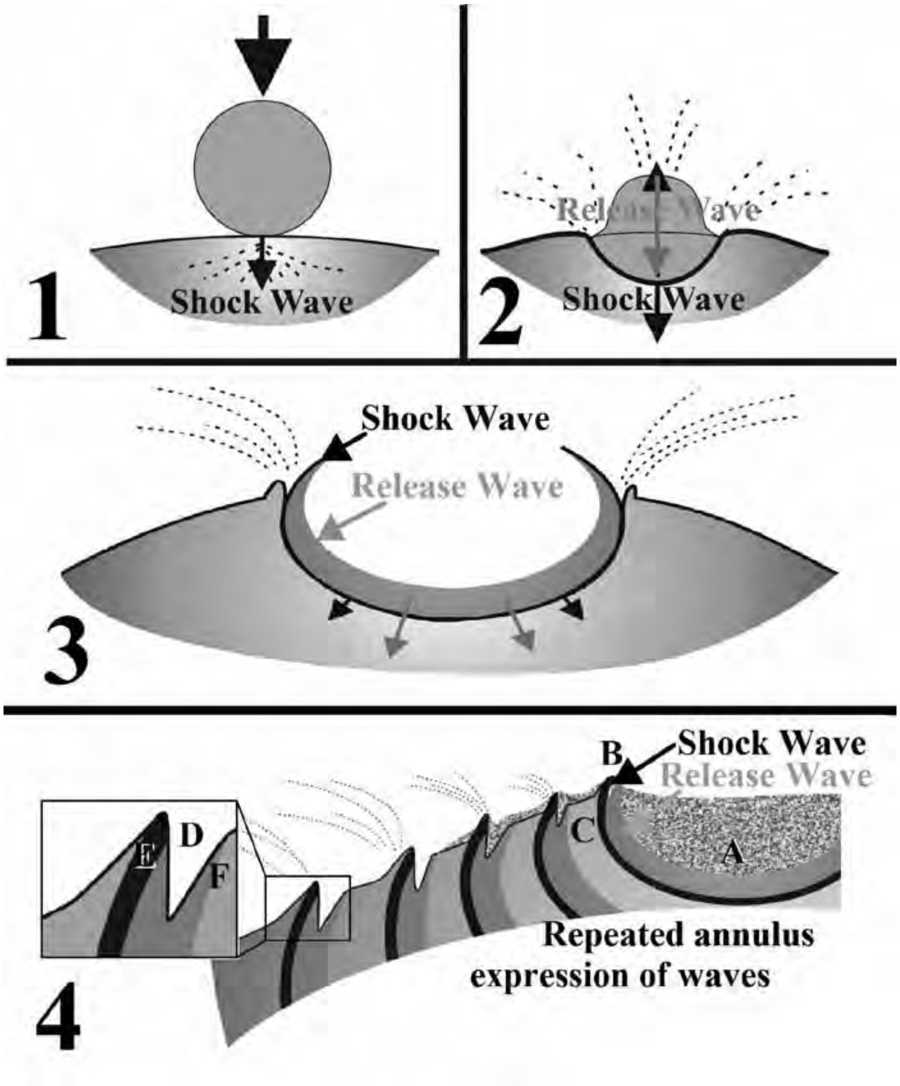

Figure 1. Diagram of an impact. (1) Impactor strikes the surface of the earth, and speed and mass are converted to work as a shock wave starts to penetrate into the substrate. (2) Energy is reflected back into the impactor, vaporizing it. (3) This produces the release/rarefaction wave that propagates after the shock wave, creating a paired shock-release wave. (4) The shock and release waves continue outward, interacting with the boundary layer of the crust surface according to the law of the wall.

Mechanics of Impacts and Cratering

The first studies of impact mechanics were modeled on underground explosions, done to test the effects of bombs on population centers. Norman et al. (1977) reported on work done by G. H. S. Jones of the Canadian Defense Research Board. In the test, 500 tons of TNT were detonated at the surface and the resulting shock waves observed. Though informative, the test was only partly helpful; actual impact mechanics are quite different.

Osinski and Pierazzo (2013) described the sequence of events during an impact. When a body strikes Earth, it produces a shockwave that propagates into the substrate. The energy of a shock wave depends on the speed and mass of the impactor, and since impactor velocities can exceed 25 km/sec and large impactors can measure tens to hundreds of kilometers in diameter, energy levels are very high—sometimes exceeding 100 GPa. When the impactor strikes (Figure 1.1), a shock wave both propagates outward at supersonic speed and rebounds back into the projectile (Figure 1.2). When it reaches the far surface of the projectile, it is reflected as a rarefaction or release wave, usually vaporizing the impactor. Since this happens before the body can penetrate more than 2–3 diameters into the substrate, relatively little energy is transferred in its destruction. Instead, the crater forms through the displacement of a paired shock and release wave that moves outward through the matrix (Figure 1.3).

Jones et al. (2002) modeled this release wave (Figure 2); where the shock portion reaches pressure of over 3.0 Gigapascals above normal, the release portion sees a dramatic pressure drop to more than 2.0 Gigapascals below normal, resulting in a wave form on the surface that reflects the alternating topography predicted by law-of-the-wall interactions. Figure 3 shows an energy-vs.-time cross section of the same phenomenon.

Energy waves from impacts thus have three parts: the *shock wave*, with its sudden spike of pressure, the *release wave,* which moves into and out of negative pressure, and the *rebound*, which appears as a more even pressure wave.

Law of the Wall

Boundary effects are important in many physical processes. In sedimentation, this interaction is called "the law of the wall" (Julian, 1998; Pope, 2000). Where two objects are moving relative to each other, a thin layer against one boundary is affected by the friction of the nonmoving boundary. This is seen in something as simple as dust on a country road. In slow motion, there is a stuttering at the wave edge shown by the "puffs" of dust coming out from under a tire. Likewise, in a flowing stream, dye near the stream boundary will "puff" outwards, reflecting a continuous stream of intermittent turbulence.

I propose that this principle can be applied to shock-release waves. When a high-energy impact wave encounters lithologic boundaries, the rock is sufficiently brittle and the boundary so thin that when the stress from the pull of the

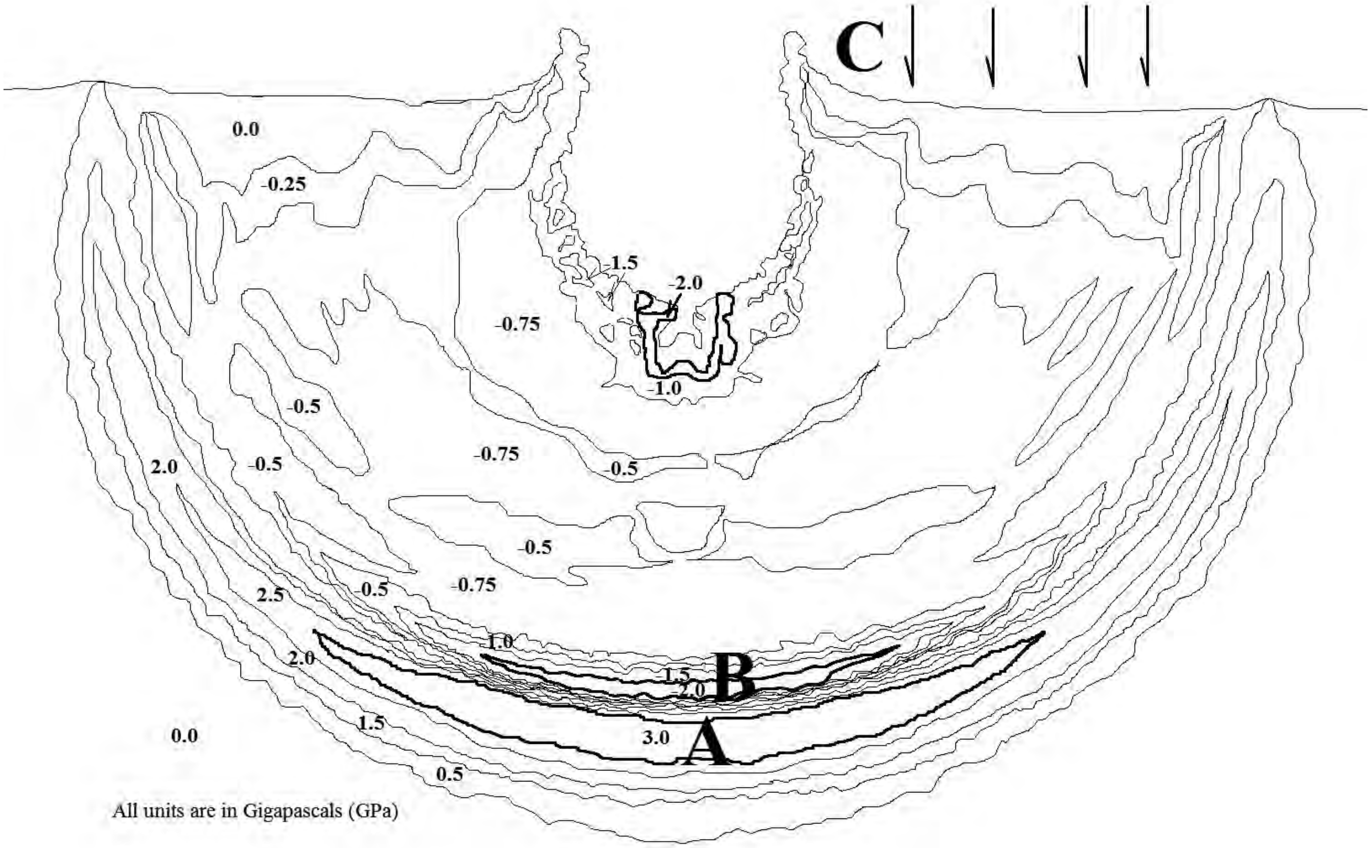

Figure 2. Diagram of a mathematical simulation of an impact shock-release wave, showing the alternating pulse caused by the shock (A) and release (B) portions. All units in Gigapascals (GPa). Arrows at (C) show repeating alternation of shock and release pulses at the boundary interaction.

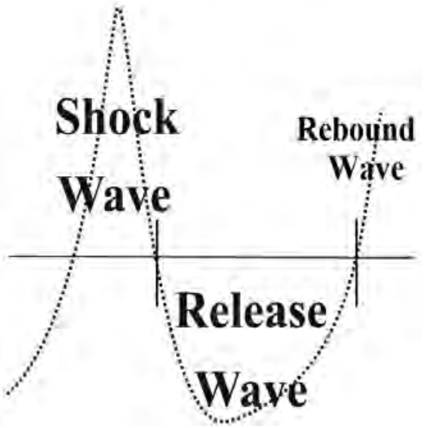

Figure 3. Proposed structure of a shock/release wave, with pressure energy over time as modeled by the author, based on the configuration of waves in Figure 2. Time is usually expressed in microseconds and pressure in gigapascals.

wave motion exceeds that of friction, the wave will release and jump ahead. We see the effect in Figure 2 in the bumps into the 1.75 GPA layer at (C).

Since a shock wave is continuous passing through the surface of the Earth, I propose that the shock wave would show turbulence at lithologic boundaries, pushing and pulling at semi-regular intervals, leaving a more pronounced imprint (Figure 1.4). This can be viewed as recurring annuli around craters of all scales as we will see in our examples. At a large enough scale, these would form mountains and valleys (Figure 1.4, D, E, F, and Figure 7A). In the case of multiple impacts, interference would be expected as cumulative affect (Figure 6a, b and c).

Examples: Lineaments as Impact Imprints

An impact produces an original crater rim (OCR) that is rapidly filled (up to 80%) by falling ejecta (French, 1998). Additional infill is typically vapor condensate and the fallback from other craters. The OCR is the first expression of the shock and release wave in the surface. These waves then leave a continuing signature in the surrounding countryside of concentric lineaments, annulus (Figure 1.4).

This imprint is expressed at the surface with a sharp topographic rise on the leading edge, a trough or "release valley," and a smaller rise exterior to both (Figure 1.4D). The release valley may look like a gap between the two elevations (Figure 3), or it may be manifested by strata dipping into a low spot. There is evidence for both at different locations. Variations may result from interference from multiple shock-release waves, accompanying deformation that can be either plastic or brittle. Two examples of these features are seen at Unaweep Canyon and the TONCK lineament.

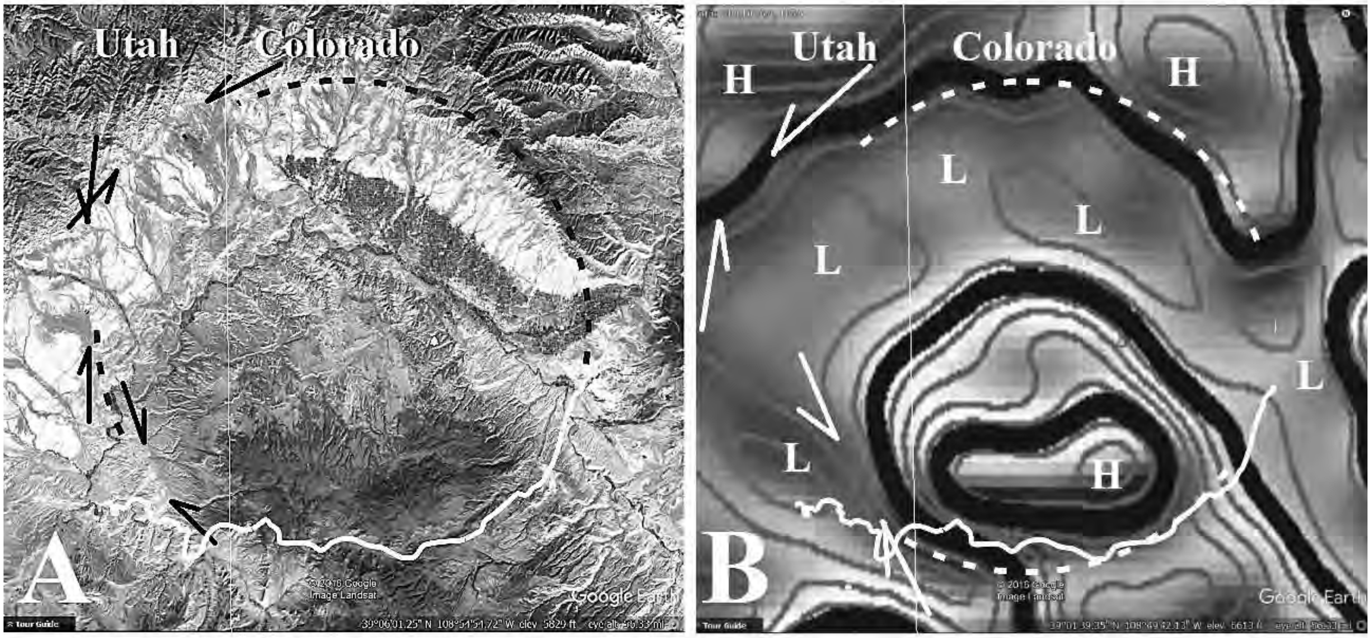

Figure 4. (A) Google Earth images of the northern Uncompahgre Plateau (Pinon Mesa) with Unaweep Canyon at the border between Utah and Colorado. Irregular white line (lower right) shows path of canyon. Dashed path are linears that follow circular lineament. Arrows show locations where color changes show linears that are concentric to lineament. Lineament is continuous to canyon. (B) Global Gravity Anomaly (GGA) map of same area. Location of Unaweep Canyon mirrors the gravity low cutting through general high of the Uncompahgre. (A: 2015. 39°06'01.25"N, 108°54'54.72"W. December 13, 2015. Accessed 09/28/2016. B: 2016. 39°01'39.35"N, 108°49'42.13"W. Accessed 09/28/2016.)

Unaweep Canyon

Located in the north end of the Uncompahgre Plateau, Unaweep Canyon runs northeast to southwest. There are no associated faults or rivers to explain its origin. Two small, underfit streams currently drain the canyon, flowing in opposite directions. The northeast terminus intersects the outflow location of the deeply-entrenched Gunnison Canyon, dropping 1,400 ft. (427 m) over the last 3.8 miles (6 km), and only 10 miles (16 km) in a straight line from Palisades, Colorado (Figure 4A), where the Colorado River exits Grand Mesa. Geologists believe that both the Unaweep and Gunnison were eroded by ancestral rivers (Hood et al., 2008).

Unaweep canyon cuts into basement gneiss and granite, overlain by sandstone and shale of the Cutler Group and Chinle Formation. The Cutler Group was apparently cut with the forming of the canyon, but the Chinle was deposited *after the Cutler, gneiss, and granite surfaces inside the Canyon were shaped* (Hood et al., 2008; cf. their figure 8). The crater that formed Unaweep Canyon contacted Earth after the deposition of the Cutler and affected the deposition of the Chinle Group.

A satellite view of the area shows many apparent arcuate lineaments (Figure 4A). In addition, a roughly circular gravity anomaly (Scripps Institute of Oceanography, 2014; Figure 4B) underlies the area (Figures 4B and 5B). The scale of the map is large, but the scale of the apparent impact feature is, too. A free-air gravity anomaly can represent changes in topography as well as changes in density in the upper crust (Figure 9). As such, gravity maps can be used to support geomorphic interpretations of lineaments.

The alignment of Unaweep Canyon suggests that it may be the result of a release wave (Figure 4). Another segment of the same circle corresponds with the Grand Valley of the Colorado (Figure 5B). This release wave may be reflected by the low gravity anomaly of Figure 5B and Figure 6, although other lineaments have modified the crust there.

If this represents an impact, there should be concentric expressions of the shock and release paired wave in the surface layer. Four such features were noted across the top of the Uncomphagre Plateau southeast of Unaweep Canyon (Figure 7B). These segments appear as topographic variations in the Chinle Formation and would have been formed about the same time as the canyon, shaping the landscape of

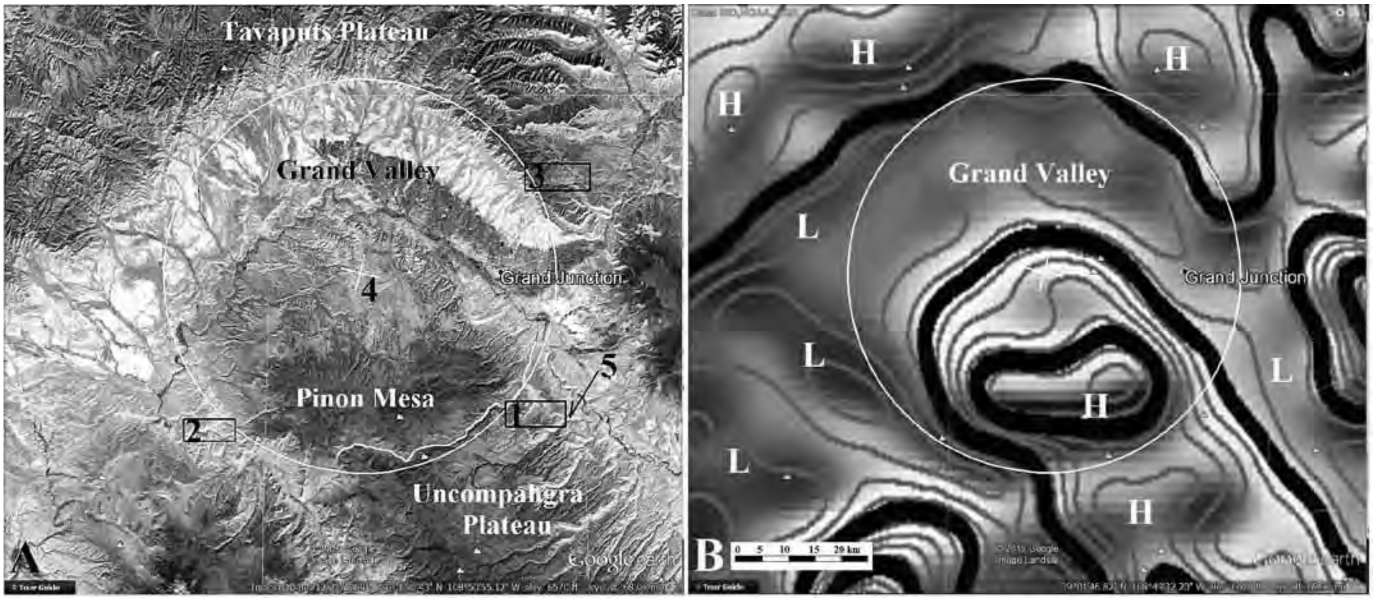

Figure 5. Possible large-scale circular feature on Google Earth and GGA map. Unaweep Canyon is traced in white just inside the inferred circular lineament in lower right of (A). Northern half of circle follows the edge of Grand Valley, with the Colorado River located along the valley's inner edge. Rectangles 1–3 are shown in detail in Figure 7. Arrow (5) indicates recurring concentric linears. (B) Circle in A overlaid on GGA map reflects both topography and lithology. L = low gravity and H = high gravity. As the isochronal pattern for the northern end of the Uncompahgre Plateau does not reflect the same shape as the topography, it is evident that some differences in near surface rock density is reflected too. This suggests that Grand Valley may be underlain by lower density rock. Center (4) is plotted at 39.063028°N, -108.855744°W. If it represents an OCR, the diameter would measure 45.23 miles (72.79 km). (A: 1969. 39°06'01.25"N, 108°54'54.72"W. December 31, 1969. Accessed 07/20/2016. B: 2016. 39°01'46.82"N, 108°49'32.20"W. Accessed 07/20/2016.)

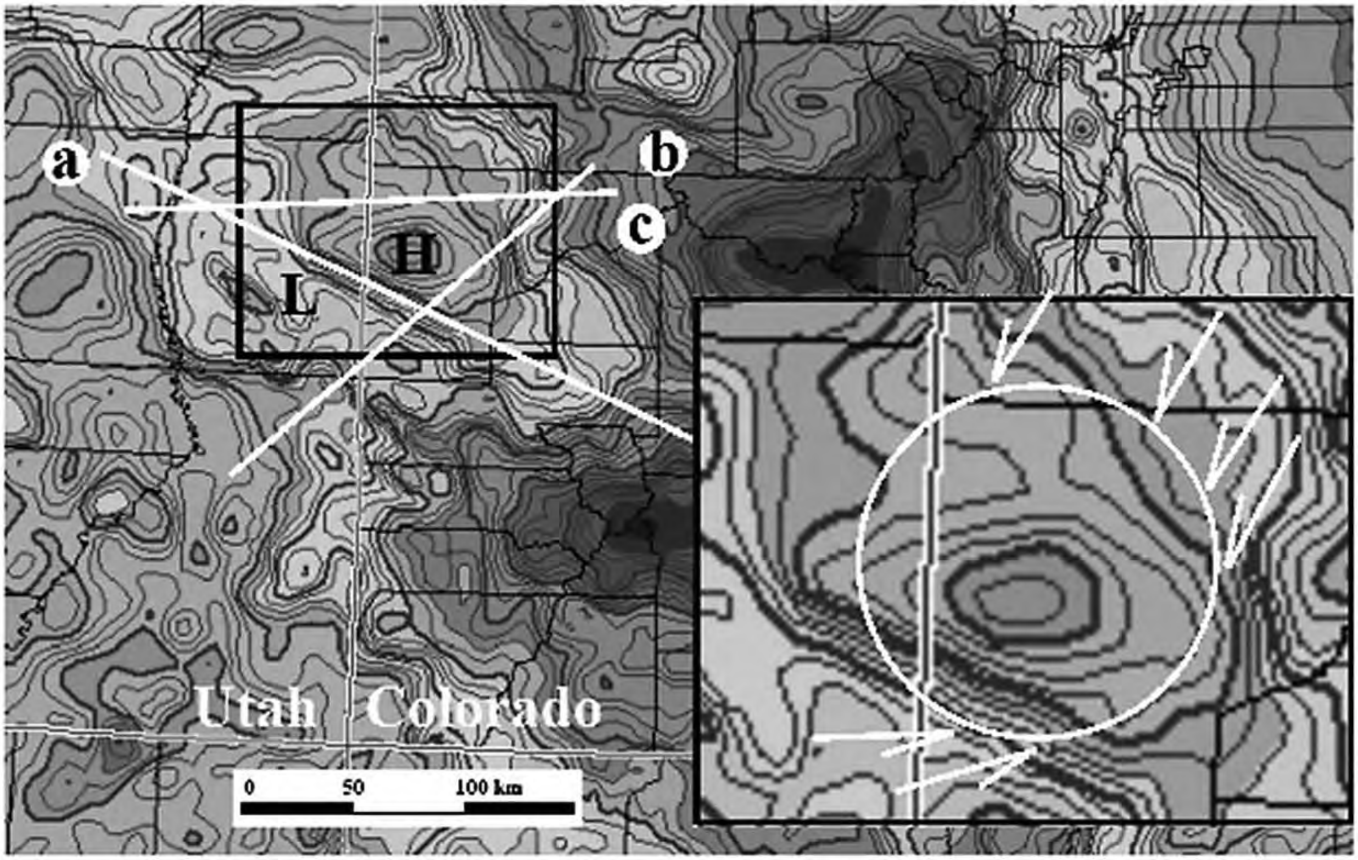

Figure 6. Bouguer gravity anomaly (BGA) map of the border between Utah and Colorado. Inset (approximately same scale as Figure 5B) shows detail. BGA reflects upper crust lithology and thickness, not surface elevation. High (H) and low (L) anomalies marked to left. The pattern differs from the anomaly in Figure 5, with gravity rise in center of circular lineament. The section between the lower right pair of opposing arrows and at the points of the remaining three arrows identify locations of abrupt gravity change, indicating displacement in crustal lithology inside the circle. White lines (a), (b) and (c) indicate prominent straight lineaments from Bouguer map, suggesting their influence on the gravity high. Modified from Dutch (2013).

the plateau. A total of five concentric lineaments were noted, labeled 1–5 on Figure 7A.

Figure 7 shows locations of five concentric lineaments, determined by alternating valleys and ridges in the Chinle Formation and indicated by arrows in Figure 7A. While the specific path of the five linears are not repeated in the other images, abundant concentric linears are continuous around the inferred circular lineament. Discontinuity suggests interference with other shock-release wave sets, but the concentric arcuate nature of the entire lineament structure is clear.

TONCK Circular Lineament

If the law of the wall applies to impact shock and release waves, annulus, circular linears concentric to an impact crater would occur outwards as shown in the Unaweep, but linears may also show within the crater as a result of additional waves generated by the fallback of material in the loose regolith of the crater. These return waves may be visible in topography or only as denser bands that show in gravity anomaly. These inner features would range from ridges of lithified sediments to density deformation within the crust itself.

An example of a very large circular feature is the TONCK structure in Texas, Oklahoma, New Mexico, Colorado, and Kansas. “TONCK” is an acronym for these states. Centered at 33.420389°N, -100.651483°W, a concentric pattern of topography and gravity changes show

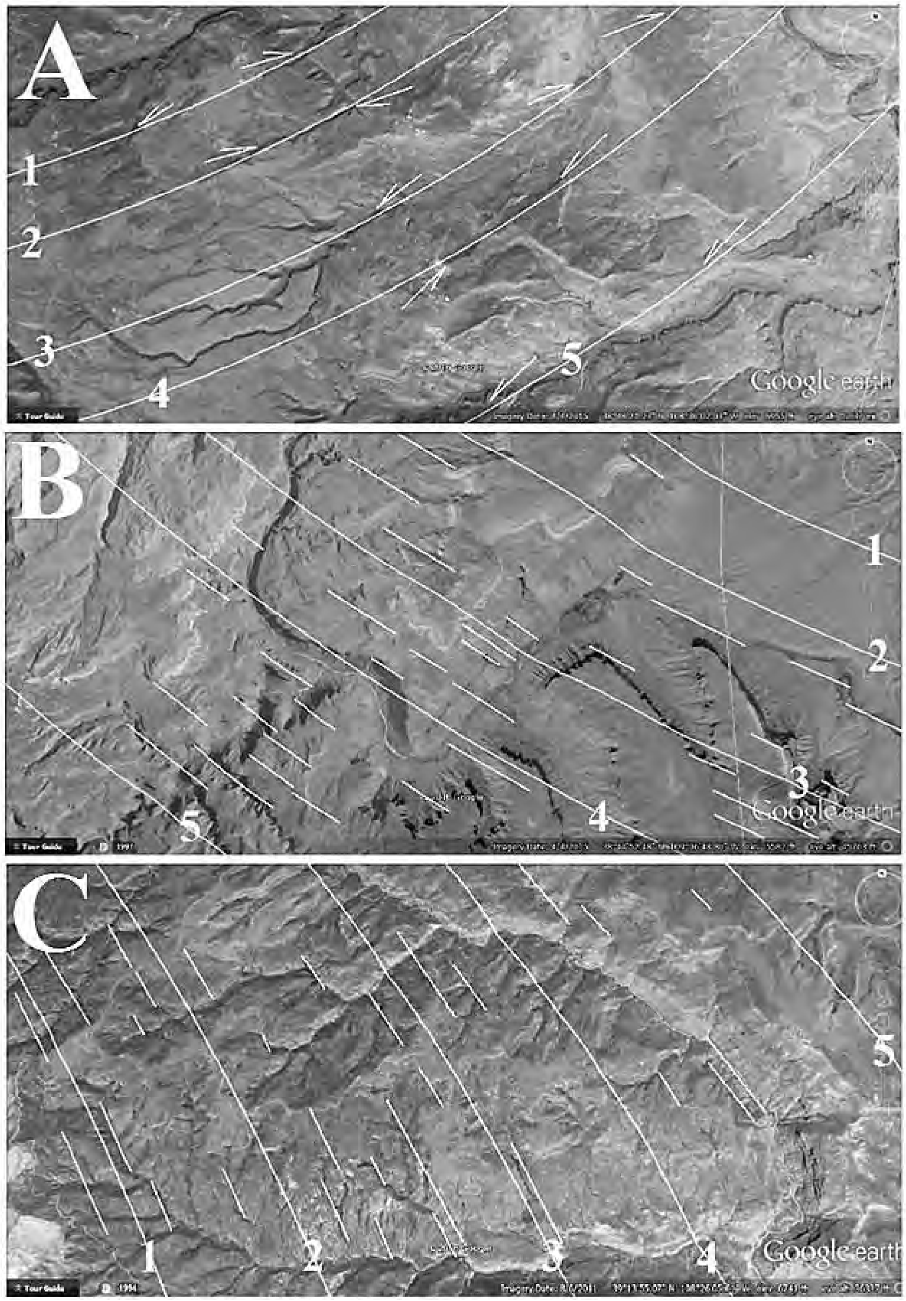

Figure 7. Google Earth detail of Figure 5A. (A) Lineaments showing five concentric rings. Arrows point to elevation changes from which lineaments were inferred. (B) Box 2 from Figure 5A. Linears are concentric to inferred lineaments. (C) Box 3 from Figure 5A. (A: 2015. 38°48'21.23"N, 108°30'02.03"W. April 4, 2015. Accessed 07/20/2016. B: 2015. 38°44'52.48"N, 109°06'48.80"W. April 4, 2015. Accessed 07/20/2016. C: 2011. 39°13'55.07"N 108°26'05.01"W. August 6, 2011. Accessed 07/20/2016.)

circular lineaments. With a diameter of 539.81 miles (868.73 km), it is much larger than the Unaweep Crater.

I consider 1a (Figure 8) to be the outer edge of the OCR, and 1b to be the ridge of the tilted block from the blowout, slumping at the crater rim. As an early crater, TONCK was affected by later impact structures. One shock-release wave will express itself in a circular lineament, but once additional wave pairs cross it (Figure 8B), the cumulative effect will be to produce a series of high and low points. Therefore, the topographic and gravitational relief expected would be points of abrupt change where multiple lineaments interact.

In Figure 8B, GGA shows 1a is the outer edge of a band of very low gravity. The Landsat image shows topography to be 800–900 ft. As Figure 9B, BGA, does not show this same low, this would be the manifestation of the release portion of the wave, as at Unaweep Canyon. If circle 1 is the OCR, then 1b would also represent the ring of tilted crustal blocks whose upturned outer edge would form the OCR. Circle 1a would be the high point of those tilted blocks.

The number of concentric linears in Figure 9A shows repeated, regular elements (Appendix). The BGR in Figure 9B shows differences in near surface lithology that agree with the general trend seen in Landsat. Few of the outer rings (Figure 10) show extensively continuous expression, which makes identification of a specific annulus more tentative. The juxtaposition of lithologic denser substrate (Figure 11) and topographic rises (Figure 10) are interpreted as the cumulative energy expression from multiple impacts' shock-release waves producing multiple intersecting linears (Figure 9B).

With circle 1 designating the OCR, lineaments A-C are interpreted as ripples inside the crater, reflected in the infill of ejecta. Such material would be pushed into concentric rings by reflected pressure waves produced by fallback and the transient crater being pushed upwards and/or breaking loose from the main body of the craton substrate. This motion would have been initiated within minutes after the emplacement of the transient crater. This gives an indication

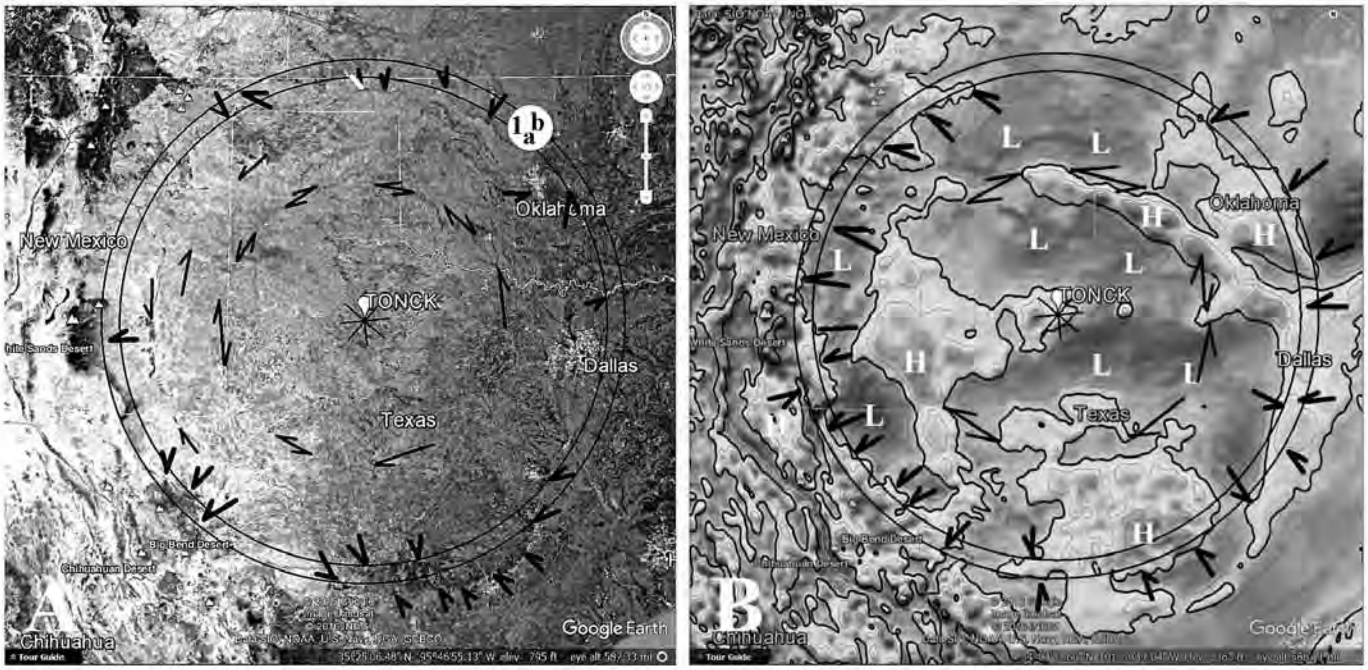

Figure 8. (A) Google Earth and (B) GGA of central United States showing the center and first circle lineaments of the TONCK structure. Heavy black arrows indicate abrupt topographic changes concentric to center. Thin arrows indicate concentric linears. (A: 2015. 35°25'06.48"N, 95°46'55.13"W. April 4, 2015. Accessed 09/30/2016. B: 2016. 34°04'37.60"N, 101°39'17.04"W. Accessed 09/30/2016.)

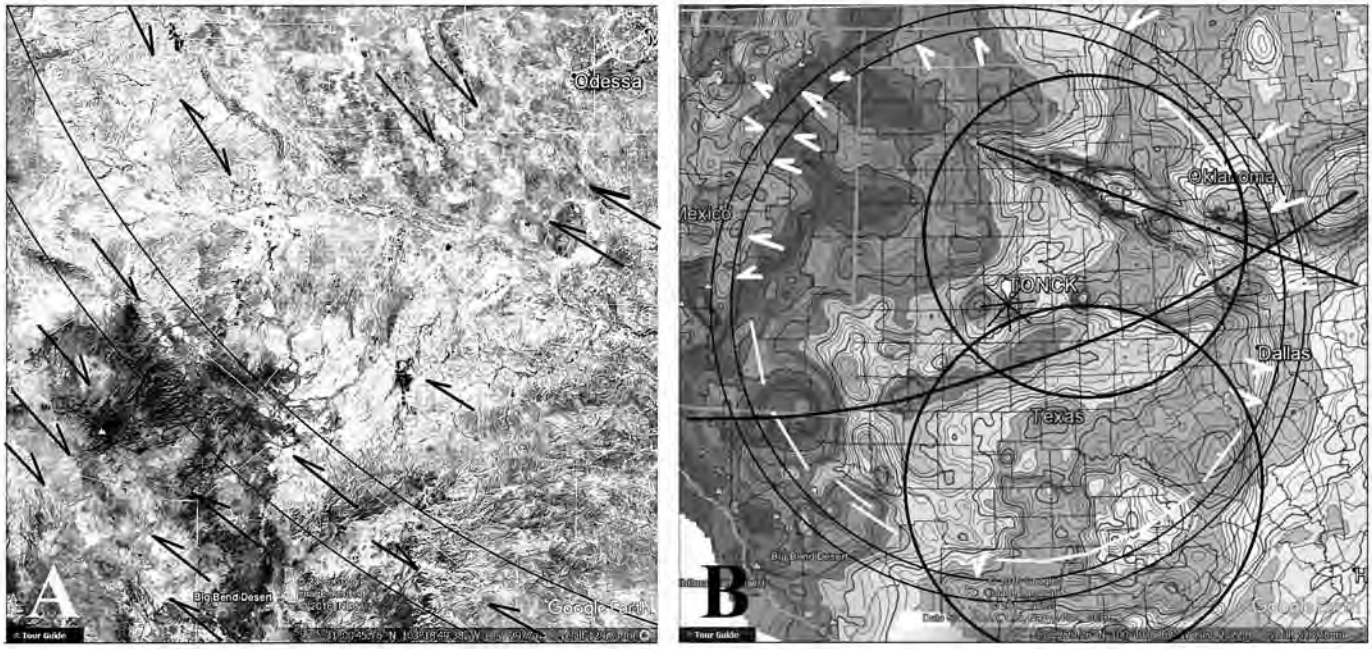

Figure 9. (A) Google Earth detail of the southwest portion of the TONCK structure concentric lines between pairs of arrows. (B) BGA with thick arrows pointing to gravity change locations. Thin white lines concentric to lineaments. Black lines show other prominent linears. (A: 2015. 31°00'45.76"N, 103°18'49.38"W. April 4, 2015. Accessed 09/30/2016. B: from Dutch, 2016.)

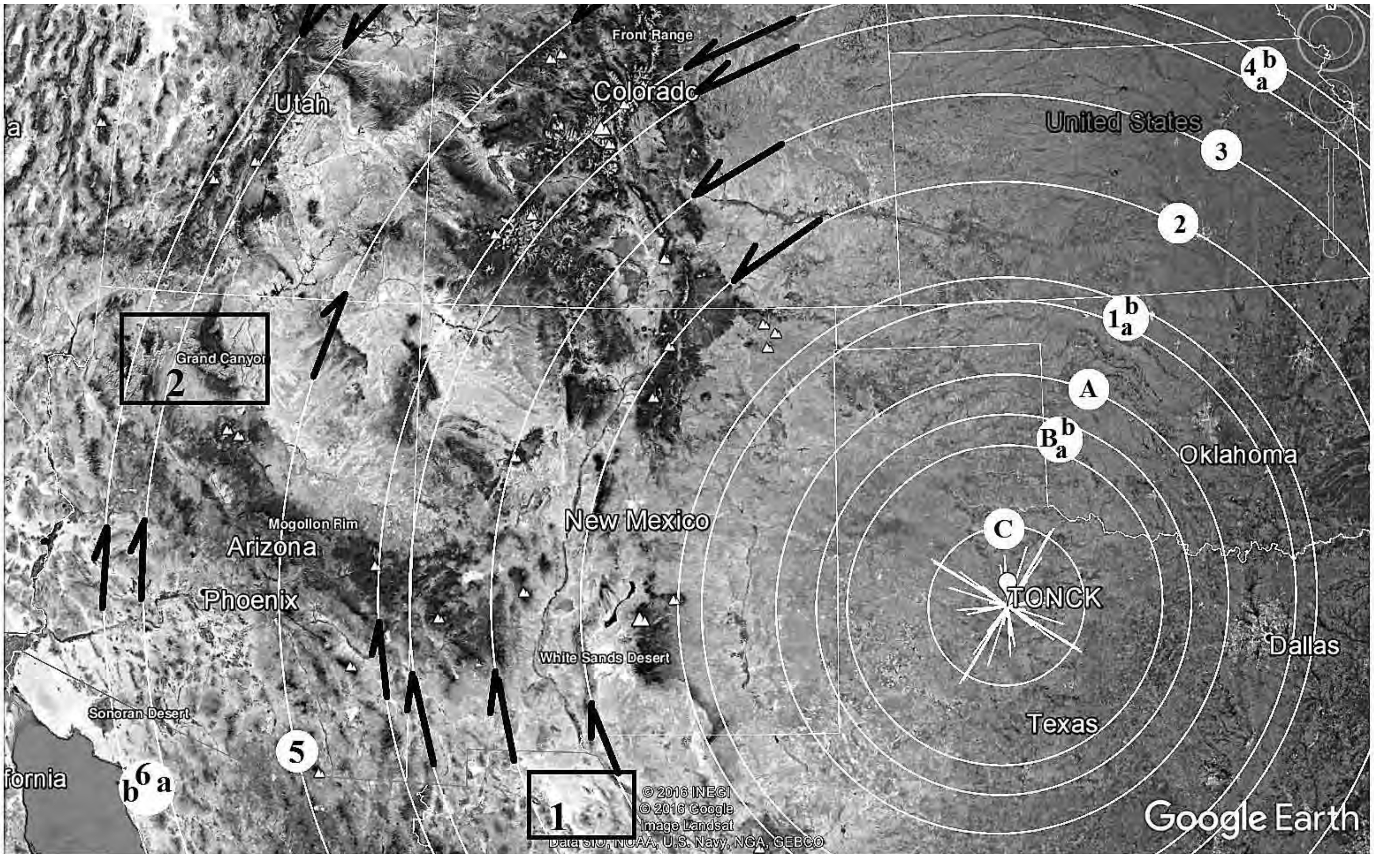

Figure 10. Google Earth image of central United States, showing the TONCK structure with concentric features consistent with shock-release waves. Arrow pairs show sections of topography concentric to TONCK center. Detail 1, see Figure 12. Detail 2, see Figure 13. (2015. 35°45'07.91"N, 104°46'39.03"W. April 4, 2015. Accessed 09/28/2016.)

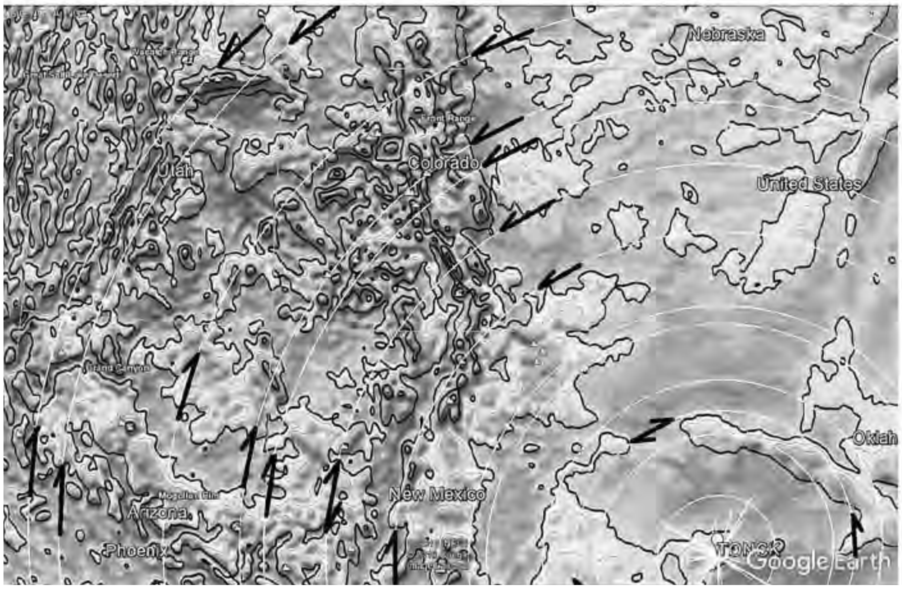

Figure 11. GGA image of northwest portion of Figure 10. Arrow pairs show lines of gravity reading changes consistent with shock-release wave expression. (2016. 37°34'52.70"N, 106°42'10.89"W. Accessed 09/28/2016.)

of how rapidly the ejecta settled back into the crater, and since the rings can still be traced as lineaments, all crater fill (including all contained fossil material) had to arrive within that time period.

Figures 12 and 13 show two details of the TONCK structure. While specific impact annulus may no longer be visible, concentric linears to that center are expressed. Some of these are seasonal stream paths in ravines. Others are cliff scarps. Some may be related to volcanism, based on the black earth around them. Lineaments have all kinds of expression in both topography and gravity anomalies. In the Grand Canyon area (Figure 13), major portions of the Colorado River and faults are concentric to TONCK. Where vegetation and cultivated land are sparse, the natural landscape still carries many traces of the

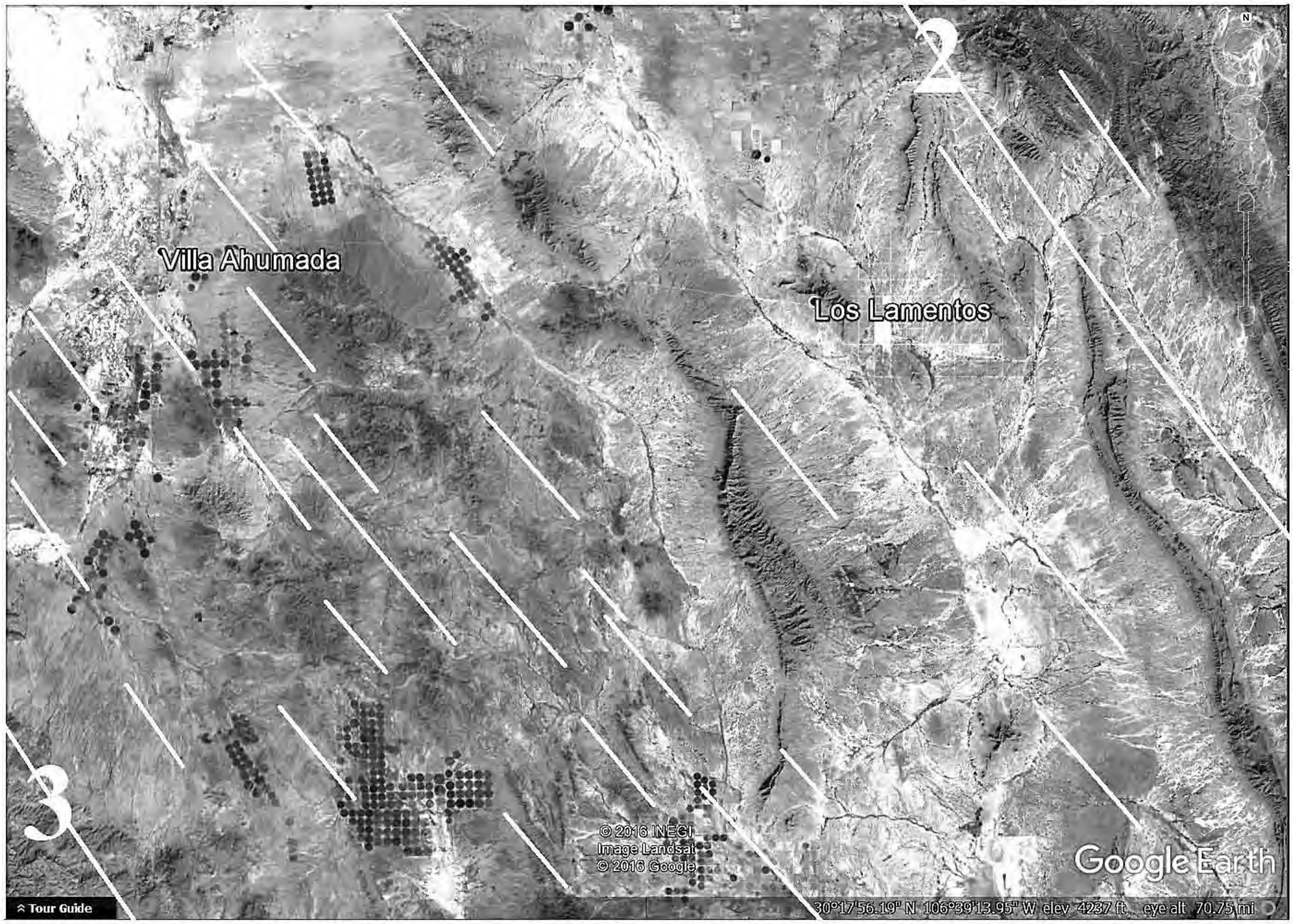

Figure 12. Detail 1, Google Earth image of TONCK detail from Chihuahua Desert, just south of Texas border. Lines 2 and 3 are annulus shown in Figure 10. Short white lines are linears concentric to the annulus and visible in this more detailed view. (2013. 30°32'50.69"N, 105°55'16.05"W. April 9, 2013. Accessed 08/08/2016.)

impact pattern. Zooming in and out using Google Earth makes it clear that *the expression of concentric lineaments is almost continuous across a given area based on the detail at which they are studied*.

Discussion

Landsat images reveal apparent lineaments that are circular at very large scales. These lineaments exhibit three characteristics: concentric elements, regular shape, and repetition. The cause of the circular linears around Unaweep Canyon and TONCK appear to be impact related. While clarity of the circular lineament of TONCK is not as clear as the smaller Unaweep structure, the TONCK is a much larger structure, obscured by later, smaller impacts. This overprinting suggests that it was an early impact. These structures appear to be impacts because their circular forms are *perfect* circles, marred only by natural irregularities at the smallest level. It is difficult to conceive of any other natural process that would create such regularity at this scale. Many of the authors listed in Table I used the same criterion to propose impacts in their study areas.

If impact structures of the scale described in this paper exist, they would have global reach and effect. The inferred TONCK structure is many times the size of recognized terrestrial impact structures.

Gay (2012) concluded that satellite imagery linears were connected to "Precambrian basement" and O'Leary and Friedman's (1978) definition connected them to "subsurface phenomenon." Following those authors, I propose that some lineaments reflect deep basement structure, but others appear to have no such connection. If impact related, larger lineaments should exhibit deep roots.

The inferred circular lineaments of the Unaweep Canyon Crater and the

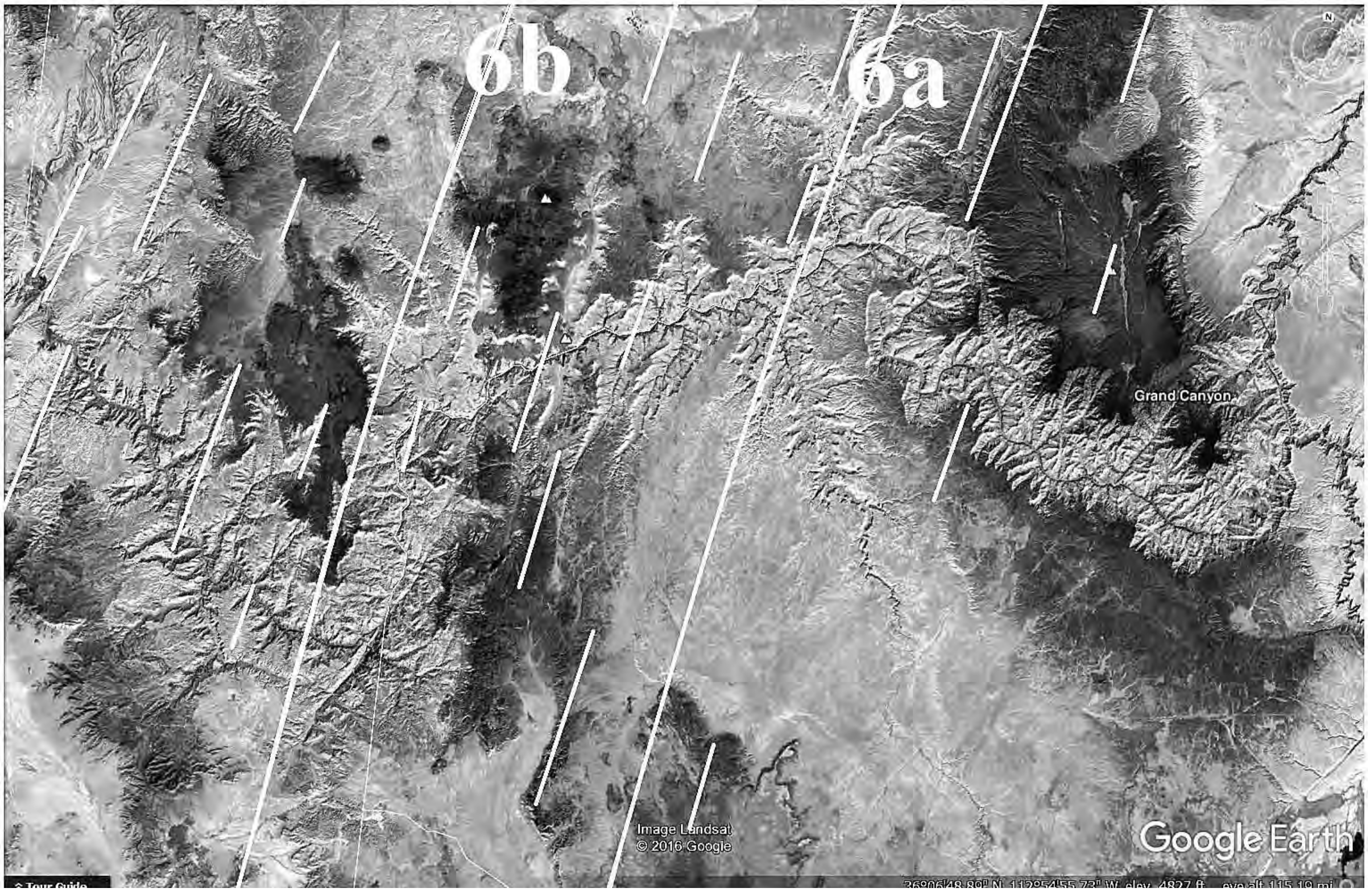

Figure 13. Google Earth image of detail 2, Figure 10, where the TONCK crosses the Grand Canyon. Direction of Linears is consistent with a significant portion of the Hurricane, Toroweap, West Kaibab Faults, and portions of the Colorado River through the canyon, suggesting the source for these faults is the TONCK crater. (2015. 33°22'29.26"N, 100°40'05.02"W. April 4, 2015. Accessed 09/30/2016.)

TONCK Crater appear to fit the four requirements as set forth in the Appendix, with the fourth being a center for impact for each. While that definition as impact craters has not been fully defended at this time, there is no known source of energy on Earth or in our solar system that would produce a crater of this shape and size, especially for the TONCK, other than an impact.

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Appendix: Seeing, Understanding and Interpreting Lineaments

Seeing inferred patterns in nature is a human preoccupation, yet pattern recognition is often subjective and difficult (Zeller, 1964). O'Driscoll (1980) proposed the existence of a "Double Helix in global tectonics" to explain Earth's lineament patterns. His conclusion was questionable, but his goal of finding a common cause behind lineaments remains important. Before lineaments can be interpreted, they must be identified. Some are obvious; most are not. How much must we see to define an inferred lineament? An *inferred lineament* is one that is extrapolated outwards from individual linears. This is a problem in "partial occlusion" (Kellman and Shipley, 1991). One person may see a feature; another randomness. Clearly, training enhances that ability, as demonstrated by those who professionally interpret satellite photographs.

This problem touches on human perception. Do these subjective or illusionary lines really exist? In the language of perception, Kanizsa (1976) and Kellman and Shipley (1991) tell us it all depends on whether we can see a purpose in our interpretation. The study of illusionary or subjective figures goes to how the human mind processes visual cues; understanding such images hinges on a perception of the whole rather than the parts (Kanizsa, 1976). Can we lead our mind to see beyond the few visual clues to a pattern or purpose behind those linears?

If all we saw of Figure A1 was the inside of the circle in A, an observer might think it was interesting short linears but without any connection. However, if the total of A was observed, all the short linear segments start to take on a larger pattern. We infer the existence of larger linears based on a recognized possible connection. Emphasizing those inferred linears may lead us to C, where a very different pattern can be recognized.

How Much Is Enough?

You view Mount Rushmore through a grove of large pines. You see a bit of

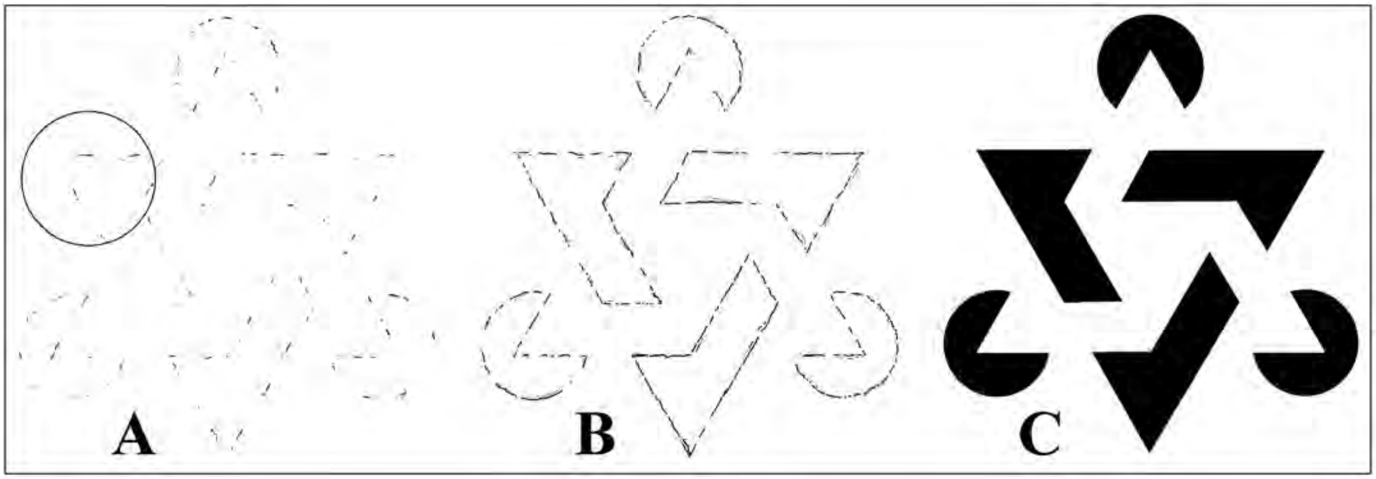

Figure A1. Progression to complex pattern. Likewise, interpretation of linears is complete only when they can be placed in the context of a larger pattern.

smooth carved rock here, the curve of a lip there, the indent of an eye elsewhere. You instinctively see even this much of a pattern to be artificial, not a result of erosion. Knowing that you are near the presidential monument, you infer the carving's presence. Partial occlusion works this way. The more familiar you are with a possible purpose, the readier you are to see the inferred pattern.

Like these patterns, lineaments are usually represented by small segments (Figure A1), linears. The human eye must fill in the pattern, which is a source of disagreement in both identification and interpretation.

One person sees a white triangle but with no edges; it is the contrasts of its absence that defines its existence. In part, it is perception of a pattern that enables additional details to be added that reinforce the larger pattern. The figure can only be viewed *as a complete understandable pattern when we see the whole and accept the existence of constituent forms we really cannot define, except in their absence*. With lineaments, the lack of specific segments may be a problem. Yet, *that void may be a clue to a larger pattern*.

Reliability

Understanding lineaments, then, requires a pattern and details that mutually reinforce each other. While the risk of circularity is a source of uncertainty, without it, lineament studies remain simplistic and confined to human scale. It is only when enough of the entire figure can be seen that the more complex pattern will be revealed. Sometimes *it is the voids that define the total picture*. The individual parts are important, but the total picture often requires an intuitive leap to the whole in order to explain the parts.

(1) *Does the figure contain repeated elements?* Cut figure A1.C through the Pac-Man shapes, and it will produce three repeated units. Natural arrangements lack symmetrical repetition without purpose or cause.

(2) *Do regular elements occur at regular intervals?* Random arrangements seldom provide regularity. This figure provides regularity in that the three circles are equal size, the two triangles are equal size, and they are equilateral triangles—having equal length legs.

(3) *Are concentric or parallel elements repeated?* Parallel elements are not a part of random arrangements without cause.

If lineaments can be used to explore ancient impacts, then we should be able to see several elements. These include arcuate to circular lineaments and parallel, concentric lineaments. Once a potential structure is defined, geological and geophysical data, such as the gravity anomaly maps discussed in this paper, can add understanding.