Ch.1: Cratering and the Earth: Clues in Lineaments

Original manuscript before revision published in
Creation Research Society Quarterly 2017, 53:191-205.

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 linears 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 propose these features were produced by impacts, and that this hypothesis may allow a better interpretation of the geomorphology.

Key words: Lineaments, Shock and Release Waves, Unaweep Canyon Crater, TONCK Crater.

Introduction

History

Finding meaningful patterns in Earth's landscapes has long been the goal of many. Galileo (1610) mapped the Moon's surface, observing mountains surrounding circular forms. He called them "protuberances and hollows" (page 8a) or "prominences and depressions" (page 9b) or "summits and cavities" (page 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" (page 12b), and later assigned them the name *crater*, for the larger Greek cup-like bowl, a krater.

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", pointing out circular lineaments in Arizona, U.S.A. Byler (1987) 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."

It is not in only recent history that lineaments have been recognized. Daubree (1879) noted sections of coastlines that were parallel or concentric across the Atlantic. Similar patterns were again mapped worldwide by De Kalb (1990). Lapworth (1892) mapped parallel elements in the dendritic paths of European rivers, and again Twidale (2004) did so in Australia. Hobbs (1904; 1911) had noted significant patterns of lines on Earth's surface, and in 1911 first used the term "lineaments" to label these forms. I am going to recognize far more circular and straight lineaments, but provide the source for them. It is with the recognition of their purpose that linears fill their important place in teaching us the true history of the earth's geomorphology.

Some authors have published maps of various specific areas which were filled with 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 arced patterns at larger scales. Sometimes they are referred to vaguely as "regional jointing" (Shoemaker 1972) patterns. Lineaments are now such a part of geology that Gay (2012, p. 3) states, "To not attempt to understand lineaments is to ignore one of the most common and basic features in geology."

Gay (2012) shows an important direct relationship between mapped linears and lineaments in the Paradox Basin, Utah, and the Comb Monocline, Utah and Arizona, U.S.A. where lineaments are not continuous but smaller linears stepping from one to another. He quoted Kelly and Clinton (Gay, 2012, p. 6), field geologists with the USGS, who stated that the monocline exhibited "straight line segments with corners" that matched crossings of the linears, before concluding: "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 basement" (Gay, 2012, p.10), a conclusion supported by Kreis and Kent (2000) and Penner and Cosford (2006). But maybe, the linears that compose the lineaments are not "reactivated shear zones from the Precambrian basement" but remnants of ghost craters from multiple recent astral-impact cratering events?

Many authors (Table I) have traced curved linears that combine to suggest circular lineaments; some extended to complete circles. This paper will do the same for two examples, showing how they conform to the energy pattern of a shock-release wave and arguing that they are the result of impacts.

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 1.1. A date ordered list of papers suggesting a significance to straight (megashears) and circular (craters) lineaments. (Table credit: Twidale 2007, with additions.)

Definition

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, validated with their repetition on gravity and magnetic maps. Two linear types are described by O'Leary and Friedman: rectilinear and *slightly* curvilinear. Lineaments inferred from *strongly* curvilinear or circular elements also occur, and I will expand the definition to cover them. As the recognized form of the linear will depending on the scale used, this paper will focus on circular lineaments, but recognize all three forms at the regional scale.

Scale and perspective are crucial to interpreting lineaments from satellite imagery. Inferred lineaments might be seen at various scales, and then patterns are clarified by zooming in or out. Details of linears require closer views; gross features require more distance. An interpreter must take all of the information, comprehend it at each level and incorporate it with a regional picture (Chapter 2). It is possible that some features will only be understood at a global scale.

For the purpose of brevity, the term "crater" in this book, unless otherwise noted, will always refer to the results of an astral body's impact event with a planet or satellite resulting in the compression in a bowl shaped depression that may or may not have filled with sediments. These features are best recognized from concentric rings moving outwards visible in the surface topography.

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. Context 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) recognize "[M]eteor 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 in unique patterns will help identify craters.

Cause of Lineament

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, Mongolia, 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 the trends of mountains were seen 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 the reality of lineaments is the human factor; some see the patterns, even using them to find ore deposits or other economic minerals, yet other scientists cannot. Saul (2015, p. 59, emphasis his), 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*.”

Others disagree (Burgener 2013; Norman et al. 1977; Saul, 2015), but explain circular lineaments 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, craters should be found at their centers. Saul (2015) and Norman (1977) both suggested that the paucity of obvious craters is caused by their destruction in continental collisions and overthrusting. But, were the missing crater destroyed or just not found because we do not understand the mechanics of cratering?

Cratering Mechanics

The first studies of impact mechanics were modeled on underground explosions, performed 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 his test, 500 tons of TNT were detonated at the surface and the resulting shock waves observed. Though informative, the test were only partly helpful; actual impact mechanics are much larger.

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 available in 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 a contact pit is formed (Figure 1.1). At contact Osinski and Pierazo thought a shock wave propagated both outward at supersonic speed and rebounding back into the projectile where it reaches the far surface of the projectile and is reflected back as a rarefaction or release wave. Lundberg (2016) suggest differently, where, like in the Barringer Crater, Arizona, U.S.A. (Shoemaker 1974), the impactor surface peels away from friction until it is enveloped in the adiabatic envelope where the rarefaction/ release (expansion) wave vaporizes it into droplets which are among the first ejecta. The rarefaction/ release wave does not need any source of generation. The expansion/release wave always follows the shock (compression) wave producing the envelope of adiabatic response behind them. (See Chapter 12 for a more complete treatment.)

The paired shock (compression) wave and rarefaction/release (expansion) wave swell outward as the adiabatic envelope forming the crater (Figure 1.4). Not blasting the ejecta ballistically outwards.

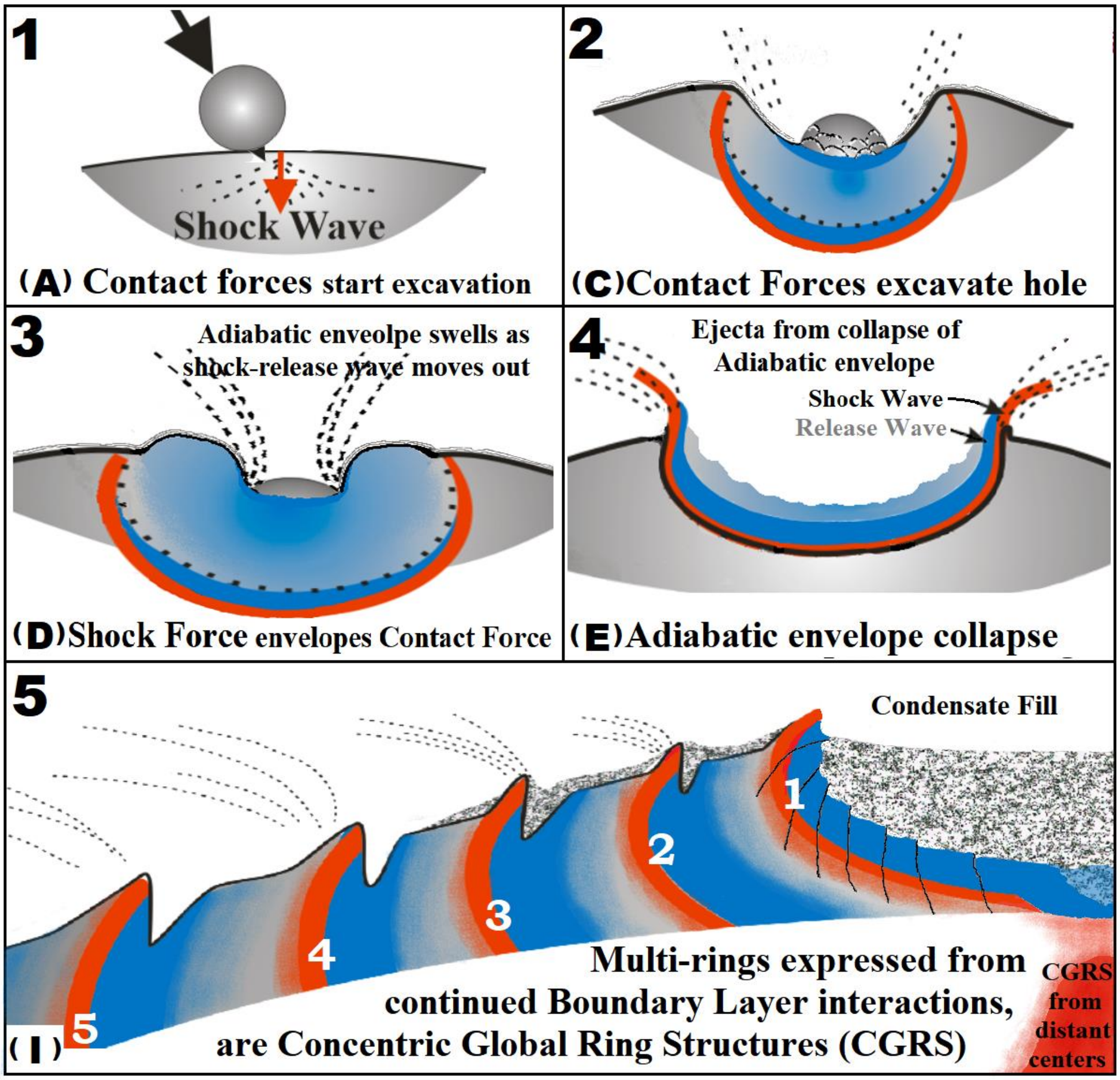

Figure 1.1: Diagram of an impact. (1) Impactor strikes the surface of the Earth produces a small amount of ballistic ejecta. (2) Speed and mass are converted to work as a shock wave starts to penetrate into the substrate. (3) Most ejecta at this point is liquid droplets until the adiabatic envelope opens. (4) With the collapse of the adiabatic envelope a vast quantity of expansion ejecta is released. (5) The shock- release wave continue outward producing repeated, annulus expressions of the adiabatic envelope at semi-regular wave length intervals as boundary layer interactions.

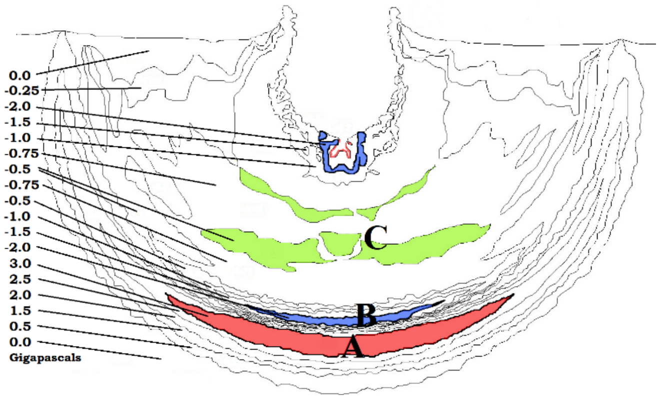

Figure 1.2: Diagram of a mathematical simulation of an impact shock-release wave, showing the alternating pulse caused by the shock (A) and release (B) portions. All units in Gigapascals (GPa) and vary from a high of 3.0 GPa to -2.0 GPa. (C) Showing the wave pulse configuration within the adiabatic envelope, and upper surface with additional small compressive and expansive wave expression. (Image credit: Jones 2002)

Jones et al. (2002) modeled this release wave (Figure 1.2) where the shock portion reaches pressure of over 3.0 Gigapascals above normal, the release portion experiences a dramatic pressure drop to less than -2.0 Gigapascals. This results not only in a wave front that passes through the substrate but leaves an energy signature in the substrate that physically conforms to the same pattern, unless enough heat is present to mask the energy signature expression. As the shock-release waves propagates outwards with its trailing adiabatic response, Concentric Global Ring Structures (CGRS) occur at regular intervals as a wave form on the surface that reflects the alternating topography arrangement of shock-compression wave ridges and release-expansion wave gullies. Figure 1.3 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.

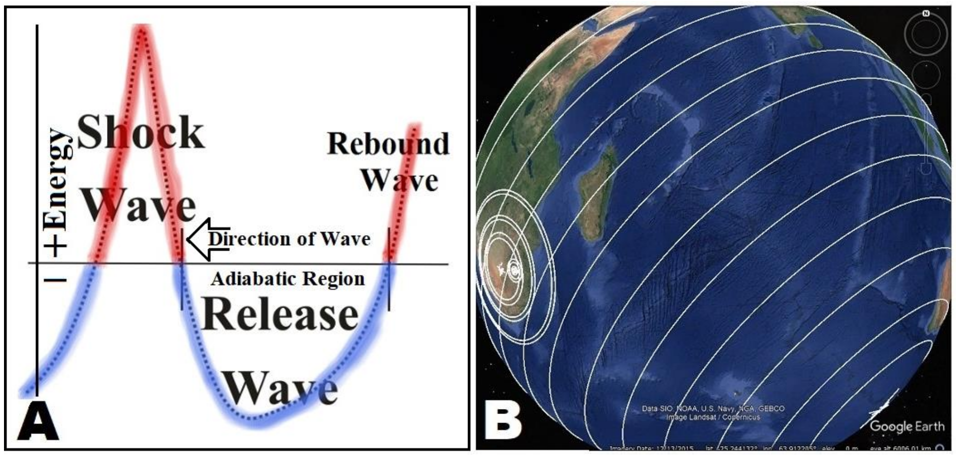

Figure 1.3: Proposed structure of a shock/ release wave, with pressure energy over time as modeled by the author, based on the configuration of waves in Figure 1.2. Time is usually expressed in microseconds and pressure in gigapascals. (Image Credit: Google Earth.)

Boundary layer interactions

Boundary effects are important in many physical processes. In sedimentation, this interaction is found when any two objects are moving relative to each other, a thin layer against one boundary is affected by the friction of the nonmoving boundary (Julian, 1998; Pope, 2000). 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 intermediate expression of the continuous energy expression.

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 wave motion exceeds that of friction, the wave will release and jump ahead. We see the effect in Figure 1.2 in the energy “puffs” even within the adiabatic envelope 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, and where it encountered and interacted with other waves, pushing and pulling at semi-regular intervals, leaving a more pronounced imprint (Figures 1.4 and 1.5). This can be viewed as recurring annuli around craters of all scales as is seen in the examples.

Examples: Lineaments as Impact Imprints

Impacts produce an original crater rim (OCR) that are rapidly filled (up to 80%) by returning ejecta (French, 1998). Additional infill is typically vapor condensate and the fallback from other craters. The OCR is the most pronounced expression of the shock and release wave in the surface. These waves then leave a recurring signature in the surrounding countryside of concentric lineaments, annulus, sometimes only producing fractures in the substrate.

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 1.5). The release valley may look like a gap between the two elevations (Figure 1.3) or it may be manifest by strata dipping into a low spot. There is evidence for both at different locations. Variations result when multiple shock-release waves set up interfering pattern in substrate that can be either plastic or brittle and has to react elastically. Two examples of these features are seen at Unaweep Canyon and the TONCK structure.

Unaweep Canyon

Located in the north end of the Uncompahgre Plateau, Unaweep Canyon runs northeast to southwest. There are no associated faults or large rivers to explain its origin. Two small, underfit streams presently drain the canyon, flowing in opposite directions to both meet the Colorado River before and after its flow around the end of the plateau (Figure 4B). The northeast end intersects the Gunnison River just prior to it joining the Colorado River and drops 1,400 ft. (427 m) over the last 3.8 miles (6 km). This precludes the Gunnison River ever flowed through the canyon, so it did not contribute to carving the canyon. On the southwestern end, the canyon and its small stream rejoins the Delores River, which soon joins the Colorado River, and gives no indication either of these rivers once flowed through the canyon. Yet, without any connection to major river's paths, geologists believe that both the Unaweep and Gunnison canyons were eroded by ancestral rivers (Hood et al., 2008) because they see no alternatives.

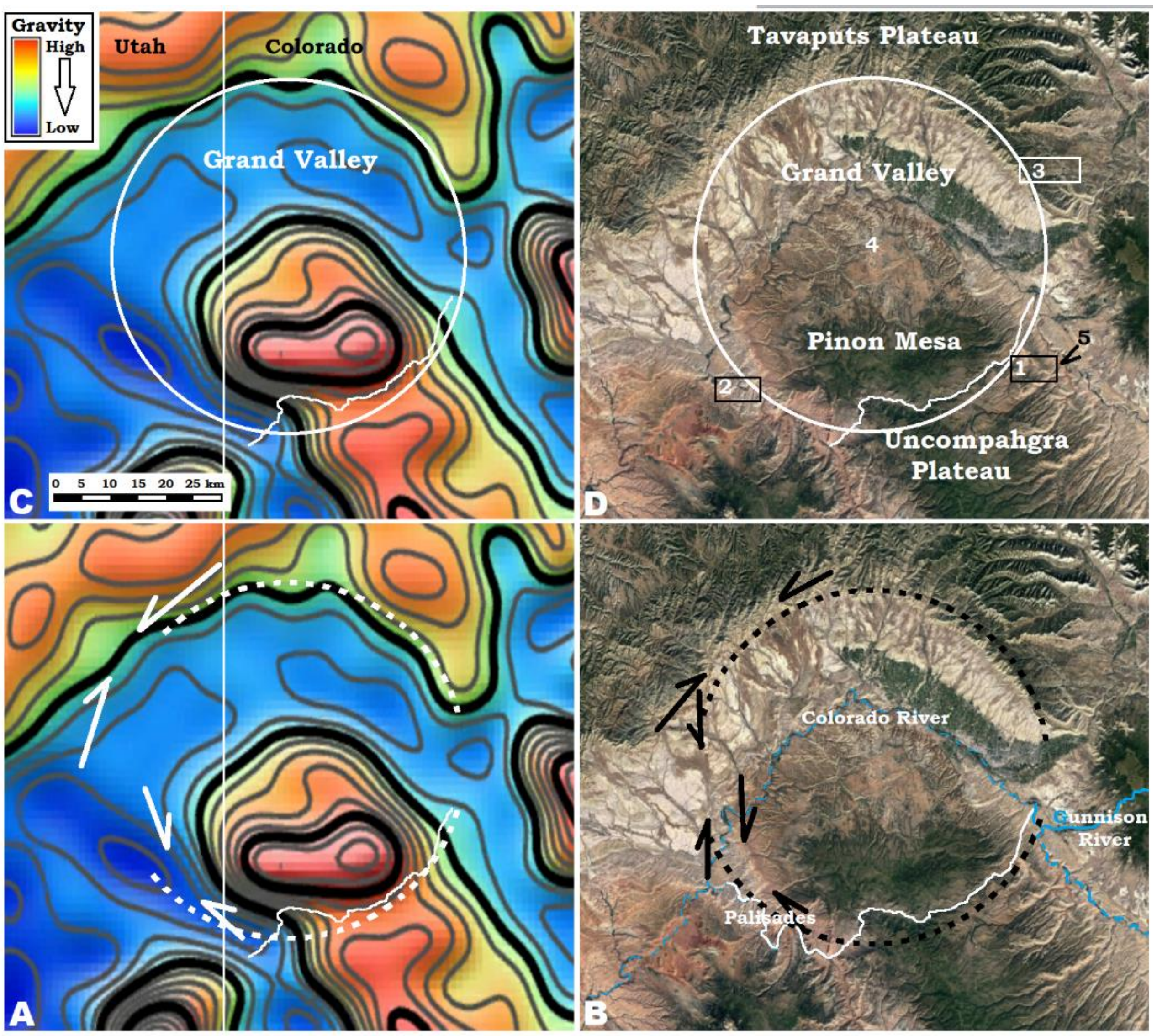

Figure 1.4: Google Earth images (A) Global Gravity Anomaly (Scripp's 2014) of the northern Uncompahgre Plateau (Pinon Mesa) with Unaweep Canyon near the border between Utah and Colorado. White line shows stream path in the canyon. Dashed arced linears are circular lineament of possible crater. Arrows show locations where color changes show linears concentric to that lineament. (B) Landsat image showing topography Unaweep Canyon runs through bisecting Uncompahgre Plateau. (C) Global Gravity Anomaly map showing the circular linear continuity between the Unaweep Canyon and Grand Valley. (D) Colorado River hugs and almost undercuts Uncompahgre Plateau. Locations of details indicated. (Image Credit: Google Earth 2015. 39º06'01.25"N, 108º54'54.72"W. December 13, 2015. Accessed 09/28/2016.)

In Bouguer Gravity maps linears are seen at locations of change in gravity patterns. In Figure 1.5 this is most markedly seen in the straight linears a, b, and c, which the reader can extend far beyond the lines drawn. Changes for the circle, seen in the detail, are less pronounced.

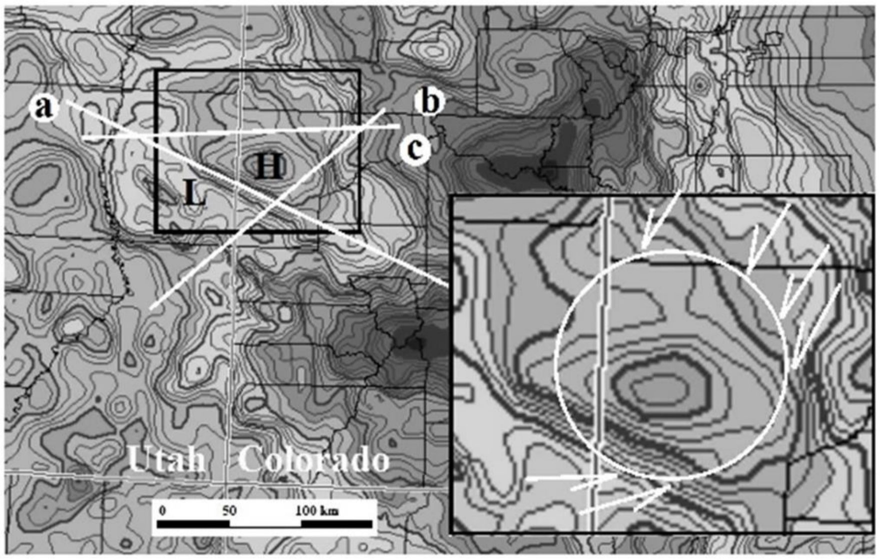

Figure 1.5: Bouguer gravity anomaly map of the border between Utah and Colorado showing location of detail. Inset detail is approximately same scale as Figure 1.4. Bouguer gravity anomaly reflects upper crust lithology and thickness, not surface elevation. The pattern differs from the anomaly in Figure 1.4; 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 not seen in Global Gravity Anomaly which contributed to expression of release wave valleys low gravity. (Image credit: Modified from Dutch 2013).

- Shape of plateau in gravity reading does not reflect the same shape seen in topography. Most distinctive is the circular low spanning both the granitic structure of the plateau and the sediments of Grand Valley, Figure 1.4C. Density was not lowered to the same absolute level, but both were lowered. Small isthmus of lighter blue continues the linear of the plateau into a higher spot of density in the Tavaputs Plateau just into Utah, showing the raised linear of the plateau was diminished but not cancelled. This suggests that Grand Valley is underlain by lower density rock, and the release wave decrease in the area of Unaweep Canyon only decreased the energy contributed there.
- Figure 1.4 D.4 marks the center at 39.063028°N, -108.855744°W of the circular lineament. If the canyon represents the release wave valley (Figure 1.6), Figure 3 shows it follows the shock wave which would locate the transient rim on its exterior. The rim diameter would measure 45.25 miles (72.8 km).

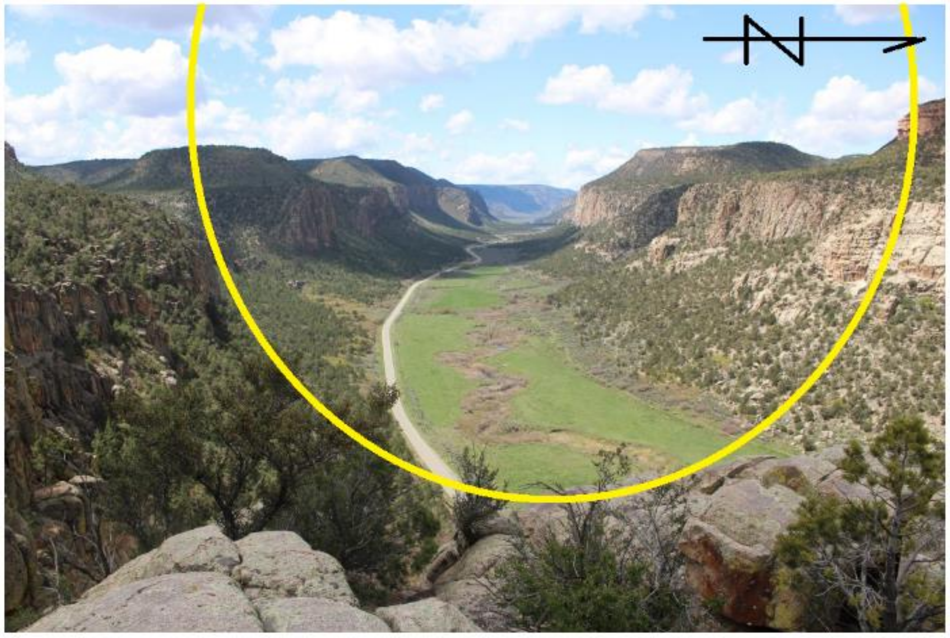

Figure 1.6: The general U-shaped profile seen looking west in Unaweep Canyon. The U-shaped valley is consistent with the adiabatic response resulting from the release wave within an annulus to the crater. Impact center is to the north. (Image credit: Karen Hartley, sharinghorizons.com, with permission.)

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.

If Unaweep Canyon is a release wave valley, originating as an impact producing a point of stress, other concentric expressions in fractures and other linears in the surface topography may be seen. Four such features are indicated by double arrow across the top of the Uncomphagre Plateau southeast of Unaweep Canyon (Figure 1.7A). These segments appear as ripples and breaks in the Chinle Formation, but may have their origin in the underlying Cutler Group. These variation would have been formed about the same time as the canyon, shaping the soft sediments then forming on the plateau. A total of five concentric lineaments were noted, labeled 1-5 on Figure 1.7A.

Using the same center, these five concentric linear features were extended around the Unaweep crater. While the precise path of the five linears are not repeated in Figure 1.7B & C, abundant concentric linears do occur all around the inferred circular lineament. The discontinuity between linears suggests constructive and destructive energy expression as seen in overlapping ripple sets. The concentric arcuate nature of the entire lineament structure following reginal fracture pattern is evident.

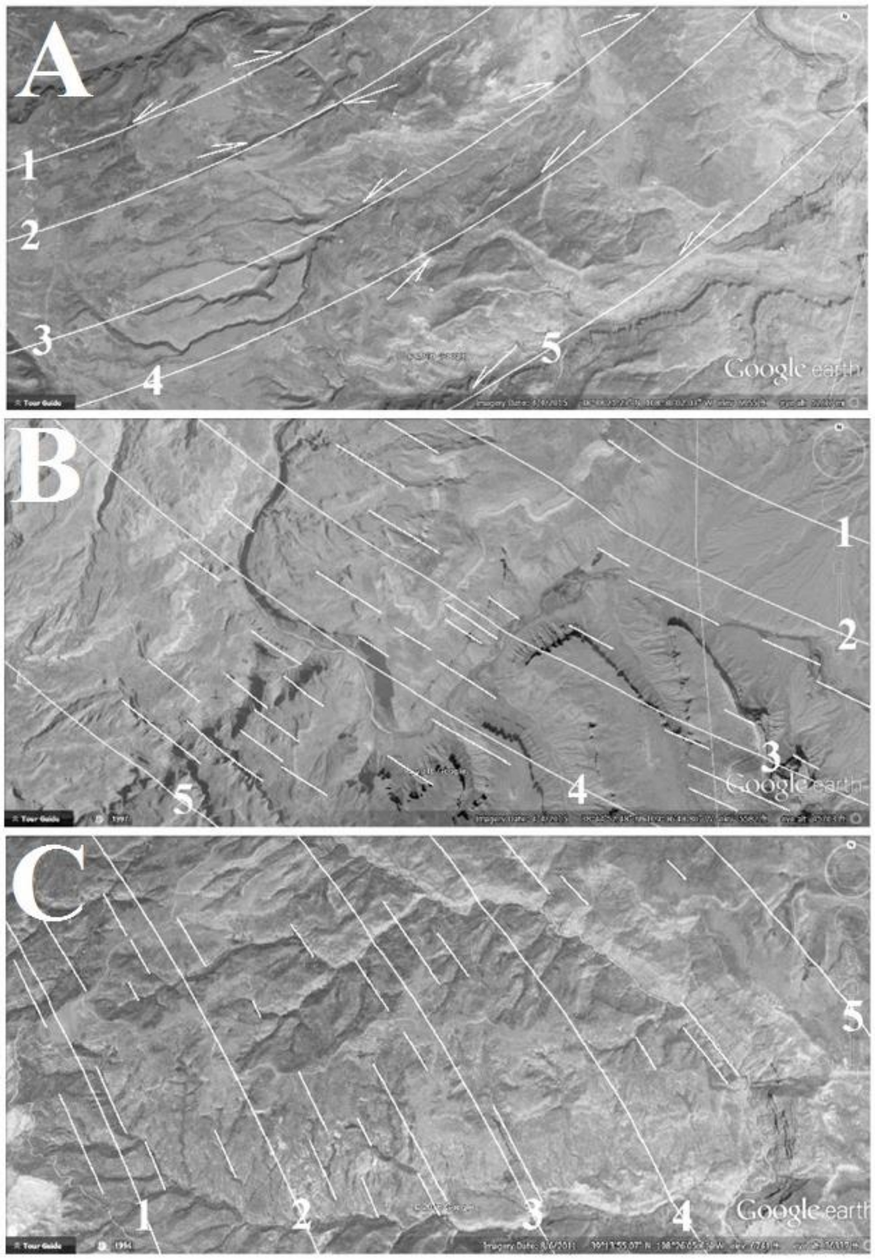

Figure 1.7: Google Earth detail of Figure 5D. (A) Lineaments showing five concentric rings. Arrows point to elevation changes from which lineaments were inferred. (B) Box 2 from Figure 5A. Linears are concentric to inferred lineaments. (C) Box 3 from Figure 5A. (Image credit: Google Earth 2015. Accessed 07/20/2016.)

TONCK circular lineament

If boundary layer interaction applies to impact shock-release waves, annulus, circular linears concentric to an impact crater, which occur outwards as shown in the Unaweep, then linears may also show within the crater. They are a result of additional waves generated by vibration of the cratering bowl, resonating in fallback material of loose regolith in the crater. These resonating waves may be visible in topography or only as density bands that show in gravity anomaly. These inner features would range from ridges of lithified sediments to density deformation within the sediments.

An example of a very large circular feature is the TONCK structure in **T**exas, **O**klahoma, **N**ew Mexico, **C**olorado, and **K**ansas. “TONCK” is an acronym for these states. Centered at 33.420389°N, -100.651483°W, a concentric pattern of topography and gravity changes show circular lineaments. With a diameter of 539.81 miles (868.73 km), it is much larger than the Unaweep Crater.

I consider the OCR rim to be between 1a and 1b in Figure 1.8. As a mid-sequence crater, TONCK was overprinted by later impact structures. One shock-release wave will express itself in a circular lineament, but once additional wave pairs cross it (Figure 1.8B), the constructive and destructive effect on the cumulative pattern will produce a series of high and low points like overlapping ripples in a tank of water. An example of two such additional circular lineaments are seen in the Bouguer map of Figure 1.9B. Therefore, the topographic and gravitational relief expected will often show disconnected points of abrupt change where multiple lineaments cumulatively interact, like nodes of interacting ripples.

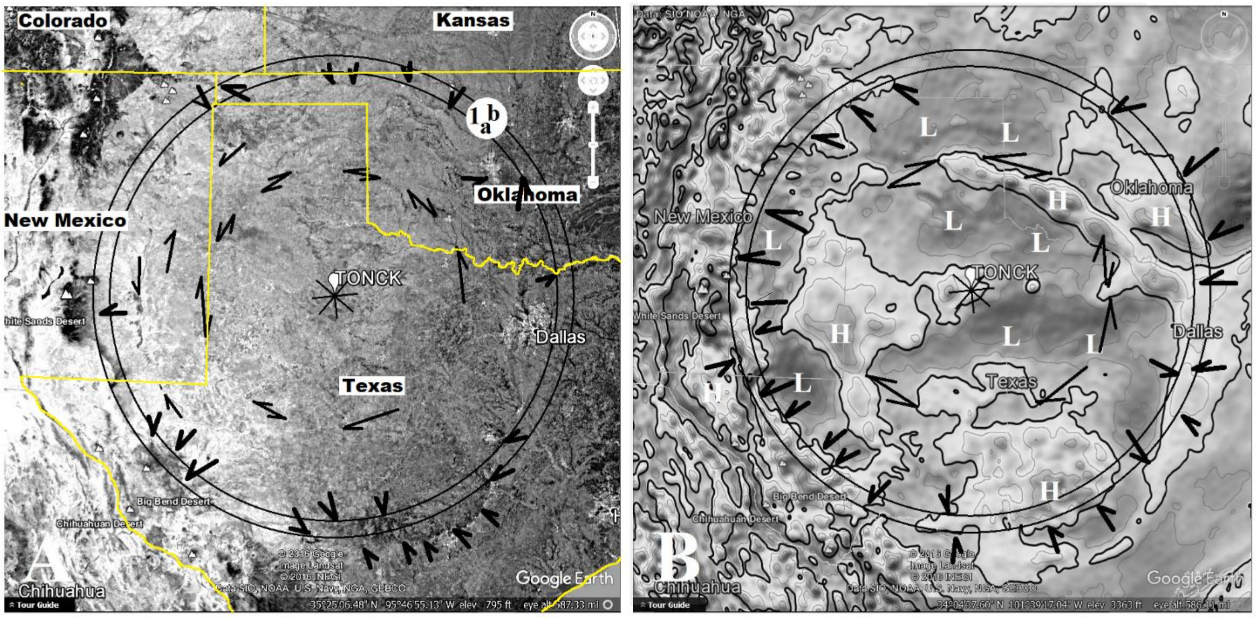

Figure 1.8: (A) Google Earth and (B) Global gravity anomaly map of central United States showing the center and transient rim lineament of the TONCK structure. Heavy black arrows indicate abrupt topographic and gravity changes concentric to center. Thin arrows indicate concentric linears. (Image Credit: Google Earth 2015, accessed 09/30/2016.)

In Figure 1.8B, Global Gravity Anomaly shows 1a is the outer edge of a band of very low gravity. The Landsat image shows elevation to vary 800-900 ft. (240-270 meters). As Figure 1.9B, Bouguer Gravity Anomaly, 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 original rim. Circle 1a would be the high point of those tilted blocks.

The number of concentric linears in Figure 9A shows repeated, regular elements (Chapter 2). The Bouguer Gravity Anomaly in Figure 9B shows differences in near surface lithology that agree with the general trend seen in Landsat. Few of the outer rings (Figure 1.10) show extensively continuous expression, which makes identification of a specific annulus more tentative. The juxtaposition of lithologic denser substrate and topographic rises are interpreted as the cumulative energy expression from multiple impacts’ energy envelopes producing multiple intersecting linears across the entire area.

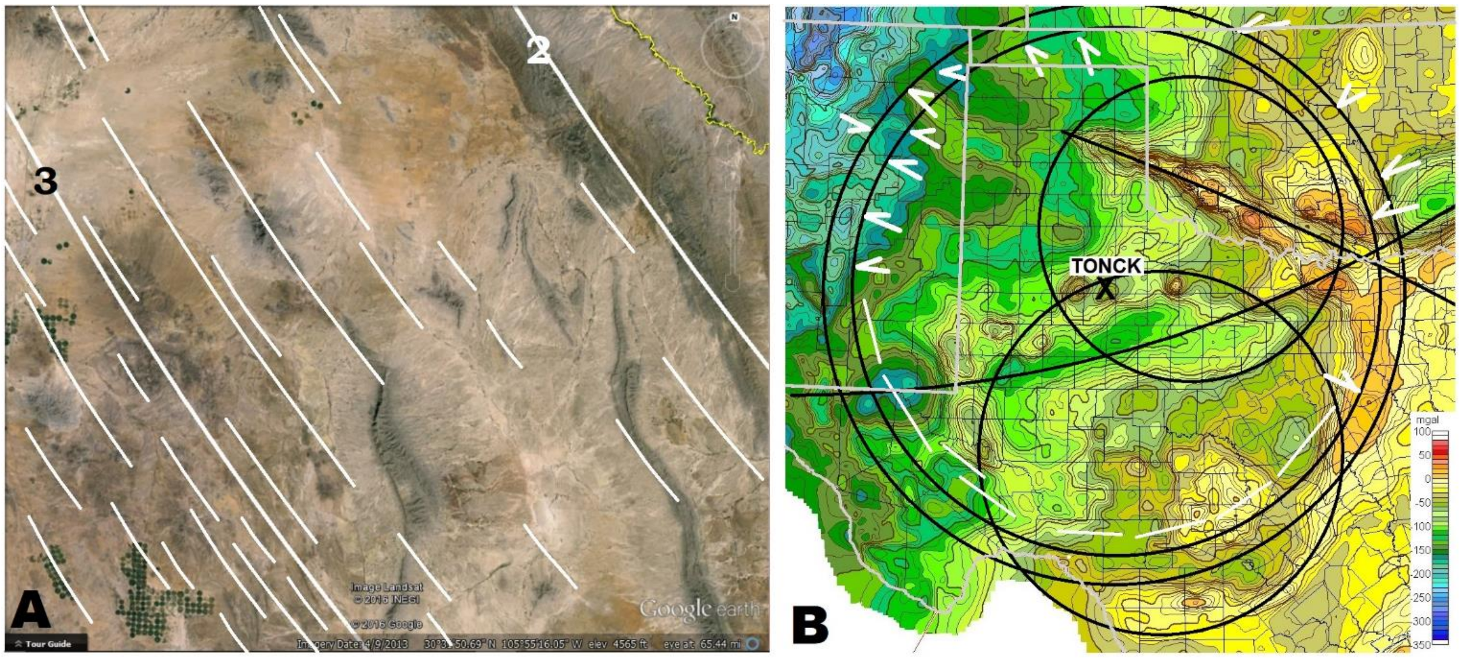

Figure 1.9: (A) Google Earth image of TONCK detail from Chihuahua Desert, just south of Texas border. Lines 2 and 3 are annulus shown in Figure 1.10. Short white lines are linears concentric to the annulus and visible in this more detailed view. Detail 1, Figure 1.10. (B) Gravity map of Texas showing circular lineaments registered in points of gravity change. Two overlapping smaller circles show the constructive and destructive effect of later impacts on the cumulative pattern. (Image credit: (A) Google Earth 2015. 31º00’45.76”N, 103º18’49.38”W. April 4, 2015. Accessed 09/30/2016. (B) Dutch 2016.)

With circle 1 designating the OCR, lineaments A-C are interpreted as ripples inside the crater, reflected as ridges in the filling ejecta. Such material would be pushed into concentric rings by reflected pressure waves produced by fallback and the transient crater being pushed upwards. This motion would have been iniated within seconds to minutes after the emplacement of the transient crater. This gives an indicates 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 frame.

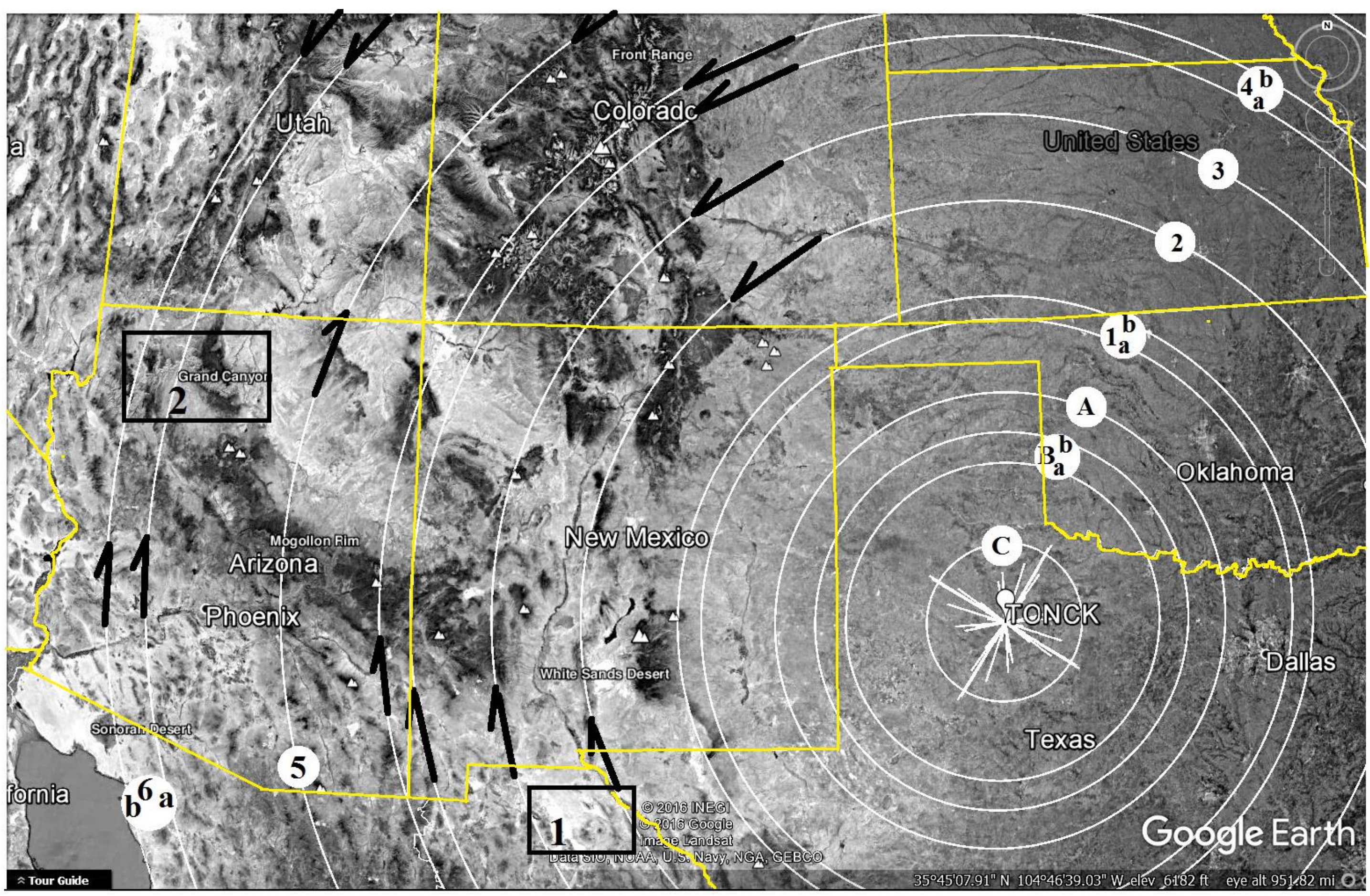

Figure 1.10: Southwestern United States showing concentric linears to TONCK structure. Locations of details are indicated by black boxes.

Figures 1.9A and 1.11 show two details of the TONCK structure. While specific impact annulus may not be easily identified, concentric linears to that center are. 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 1.11), 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 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*.

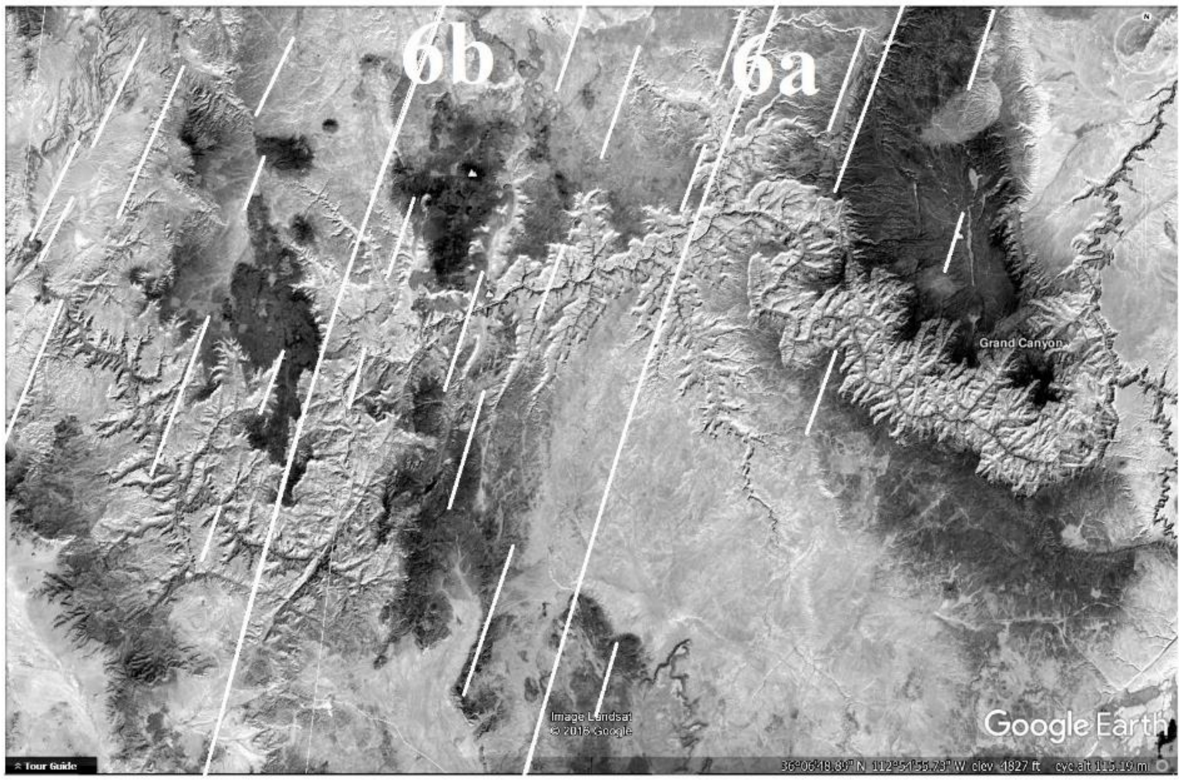

Figure 1.11: Google Earth image of detail 2, Figure 1.10, where the TONCK intersects the Grand Canyon. Direction of Linears is consistent with a significant portion of the Hurricane, Toroweap, and West Kaibab Faults, and portions of the Colorado River, showing the source for shear in these features is the TONCK crater. (Image credit: Google Earth 2015. 33º22'29.26"N, 100º40'05.02"W. April 4, 2015. Accessed 09/30/2016.)

Discussion

Landsat images reveal apparent lineaments that are circular at very large size. These lineaments exhibit three characteristics: concentric elements, regular shape, and repetition (see Chapter 2). 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 a mid-sequence 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 imagine other natural process which 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 effect. The inferred TONCK structure is many times the size of presently 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. But, before we can connect and understand them, we need to see the lineaments.

The next chapter will introduce some requirements to help interpret lineaments, and start how to relate those requirements to the energy pattern of an impact. While a reader of this book may get some information by the reading, if you are not going to open Google Earth and see the evidence for yourself, you will not truly understand the history the evidence shows. The evidence to define a circular lineament as an impact craters has not been fully defended yet, but there is no other know source of energy on the Earth or in our Solar System that would produce a crater of this shape and size, especially for the TONCK, other than an astral impactor.

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