THE WESTERN U.S. BOUGUER GRAVITY LOW/TOPOGRAPHIC HIGH: THE RESULT OF AN EARLY PLANETESIMAL INFALL? *

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ABSTRACT

It is now generally accepted that the Solar system, i.e. the Sun and its planets, formed by accretion from a cloud of swirling particles between about 4.5 and 4.6 billion years before the present. Not all the material in the particle cloud was gathered into planets and moons in the early stages, however, and impacts of this floating debris continued for eons, as witnessed by the pock-marked surfaces of all the planets and moons that we have observed to date. On the Moon, a particularly important phase of late stage impacting occurred in the period 4.0-3.8 Ga before the present, creating the large maria so visible today, even to the naked eye. As far back as 1968, Harold Urey stated: "It is very probable that the collision maria are part of the terminal stage of accumulation of the Moon and Earth," and recently it was suggested (Cohen, et al, 2000) that the visible impacts occurred in a short term event at ≈3.9 Ga, several hundreds of million years after the primary accumulation took place. On the Moon the largest of these visible late-stage basins are Orientale (900 km diameter), Imbrium (1340 km), and South Pole/Aitken (2500 km).

Many scientists are in agreement that the late stage impacting must also have occurred on Earth (Lowman, 1976, 2002; Grieve, 1980; Overbeck, 1993, among several others). In fact, Grieve, (1980) from a statistical analysis of the numbers and diameters of craters on the Moon, Mars, and Mercury, 01concluded that about 25 craters of greater than 1000 km diameter would have once been present on Earth. However, evidence of these large craters on Earth has supposedly been long ago erased by erosion, subduction, and other geological processes (Cohenour and Sharp, 1968; Carr et al, 1984; Overbeck, 1993). Or has it?

In 1968 the author recognized on a stereo 3D gravity map of the U.S. that the 2100 km diameter western U.S. gravity low was quite circular in nature (see Fig.1). He submitted a paper (1969) to a prominent journal suggesting that this might have resulted from a mare-type impact, but the idea was evidently too extreme for the reviewers of the time and the paper was rejected. Today the idea of "Earth maria" is no longer considered heretical, and I wish to present this subject to scientists of the 21st century.

I will discuss the high degree of circularity that I measured on the gravity low (0.85, according to Pike's 1977 criterion) and will show that this low corresponds to the high average topography of the western United States (averaging only 1 part in 1000, height to diameter). Thompson and Talwani concluded in 1964, from seismic studies, perhaps for the first time, that the crust and mantle of the western United States were anomalous in nature as compared to "normal" crust and mantle. In 2004, much more seismic data is available, and I will show the latest maps of upper mantle and crustal velocities (Figures 9 & 10) and crustal thickness (figure 11) that support the presence of a mantle scar resulting from the proposed impact. Additionally, supportive regional heat flow data (Figure 12) will be presented and a map of deviations of the geoid (Figure 13), plus a discussion of the limited number of deep electrical conductivity soundings that have been performed.

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The best evidence for an impact covering the western U.S., however, is still the circularity of the gravity/topographic anomaly, where the greatest number of data points are available to define it. The other data sets are not as complete. They support, but do not prove, the presence of an impact, although upper mantle velocities confirm the western boundary of the supposed impact offshore California in the Pacific, the only data set to do so.

A consequence of the impact may be the anomalous doubling of the width of the Cordillera in the western U.S. as compared to its width in Canada and Mexico (Figure 6). Also of interest are the elongated sedimentary basins that parallel the outer boundary, extending from New Mexico through Colorado, Wyoming, and Montana to Oregon (Figure 7). These basins probably parallel the outer boundary of the impact because they follow concentric faulting common to impacts. This correlation would explain, for the first time, the varying strike directions of these basins and might help to find new, buried basins.

Other anomalous circular features on Earth as shown on the latest maps of the geoid could also arise from mare-type impacts. However, none are as well studied as this one, so this could be an important proving ground. Its proof or disproof could keep geologists and geophysicists occupied (and arguing with each other) for many years.

INTRODUCTION

It is now generally accepted that the Sun and its planets and their planets formed by accretion from a cloud of swirling particles between about 4.5 and 4.6 billion years before the present. In the beginning, gas, dust, and smaller particles predominated, but as time went on, larger, solid bodies accreted from the smaller particles, and these larger bodies, because of their increased gravitational attraction for each other began to gather similar-sized bodies, some perhaps fragments of other impacted disintegrated bodies, to form the planets. The moons of the various planets and their planets formed in the same fashion, perhaps as eddies in the particle cloud, as their orbital centers were not the sun, but the parent planets. Because of gravity, all of the larger bodies took on a spherical, or near-spherical, shape, in spite of the inclusion of many irregular-shaped planetesimals of different sizes in the accretion process.

Not all the material in the particle cloud was gathered into planets and moons in the early phases, and impacts of this floating debris continued for eons, as witness the pock-marked surfaces of all the terrestrial planets (Mercury, Venus, Earth?, Mars) and moons that we have observed to date. Even the small asteroids that we have imaged on space flights are pock-marked by impacts.

On the Moon, a particularly important phase of late stage impacting occurred in the period 4.0-3.8 Ga before the present, creating the large maria so visible today, even to the naked eye (e.g. the "Man in the Moon"). As far back as 1968, Urey stated: "It is very probable that the collision maria are part of the terminal stage of accumulation of the moon and earth," although more recent work (Cohen, et al, 2000) suggests that those impacts occurred in a short term event at $\approx$3.9 Ga, several hundred million years after the primary accumulation of these bodies took place. The largest of the visible basins on the moon are Orientale (900 km diameter), Imbrium (1340 km), and South Pole/Aitken (2500 km).

The Earth's mass is 80 times that of the Moon, so Earth should have had much larger impact basins than the Moon due to its greater gravity and hence higher impact velocity. Mercury with 1/15th the Earth's mass has a 1400 km diameter late stage basin (Caloris), and Mars with 1/7th earth's mass also has a 1400 km basin (Hellas). Many scientists are in agreement that the late stage 3.9 Ga impacting would also have occurred at the same time on Earth (Urey, 1968 - see above; also O'Leary, et al, 1969; Lowman, 1976, 2002; Grieve, 1980; Overbeck, 1993, among others). In fact, Grieve (1980), from a statistical analysis of the numbers and diameters of craters on the moon and other planets, concluded that 25 craters of greater than 1000 km diameter could have once been present on Earth. However, evidence of these large craters on Earth has supposedly been long ago erased by erosion, subduction, and perhaps other geological processes (Cohenour and Sharp, 1968; Carr et al, 1984; Overbeck, 1993). Or has it?

Grieve (1980) estimated the depths of impact craters as a function of their diameters and concluded that the ratio of depth to diameter was approximately 0.5:1. Melosh (1989, p. 78) gave this ratio as approximately 0.3:1. Taking the latter, more conservative figure, a depth of around 300 km could perhaps be expected for a crater of 1000 km diameter, or 600 km for a 2000 km crater. These depths far exceed the 50-100 km thickness of Earth's continental crust (where erosion and subduction has taken place), so large impacts would necessarily have resulted in deep scars in the <u>upper mantle</u>. Remnants of these mantle scars should still be present on Earth, unless they have been completely assimilated by total mantle convective overturn, a phenomenon which would be pure speculation at this point. The proposed scars in the mantle should be detectable through the use of gravity surveys, deviations of the geoid, seismic velocity studies, heat flow measurements, and perhaps other types of studies. Magnetics would probably not be effective, since the rocks of interest all lie below the Curie depth (where the rocks are no longer magnetic) occurring at the bottom of the crust/top of the mantle.

The degree of detectability of mantle scars of large impacts would be dependent on the type of material that filled the craters and the degree of subsequent metamorphism and petrogenesis. On the moon, the maria were partially or wholly filled with basalt flows at about 3.5 Ga, some 400 million years after their initial formation (Wilhelms, 1987; Lowman, 2002). This may have been an independent event, unrelated to impact (Ivanov & Melosh, 2003). Whether the Earth maria infilled with lava or not is an unanswered question, although one worker (Glikson, 1976) proposed looking for maria on Earth by carefully studying Archean greenstone belts and mafic-ultramafic occurrences on the shields for remnants of such early flows.

Earth maria could also be partially or fully infilled with sedimentary materials, such as the ejecta from their own impacts and later ones, and subsequent normal sedimentary deposits. It has been postulated that Earth has had oceans since about 4.6 Ga when core formation and massive out-gassing of the core and mantle took place (Carr et al, 1984, p. 105) bringing water to the surface. Therefore, an ocean would have been the first infilling of the supposed several hundred kilometer depth of a large mare impact. Sedimentary infilling could have taken place by dumping of the products of erosion into the crater by ancient rivers and their subsequent redistribution by slumping, turbidity currents, and bottom currents. Lava flows could be intercalated into this sedimentary sequence. Whatever took place in those early times, the infilled material would likely exhibit a contrast in density to its surroundings, thus giving rise to a gravity anomaly.

The foregoing comments were written to lend credibility to the idea that the circular Western U.S. Gravity Low may be the site of an earth mare. This would also explain the anomalous crust and mantle of the western United States. When I submitted an early version of this paper to a prominent journal in 1969 suggesting this, the idea was evidently too extreme for the reviewers of the time and the paper was rejected. Since this idea is no longer considered heretical, I wish to again bring it to the attention of earth scientists. This may result in controversy, as do all new ideas, but I think it essential that this paper be published so that the profession has the opportunity to decide for itself whether the site of the western U.S. was the locus of a planetesimal infall or not. Reviewers who reject a paper can do a lot of harm to the profession.

Other anomalous circular features on Earth as shown on the latest maps of the geoid could also arise from mare-type impacts. However, none occur in areas as well studied as the western U.S. or have as much relevant data, so this feature could be an important proving ground. Its proof or disproof could keep geologists and geophysicists occupied for many years.

THE WESTERN U. S. GRAVITY LOW

In Fig. 1 is shown the original 1969 drawing of the interpreted boundary of the gravity low (heavy line) as located visually by the author in 1968 and hand drawn on an unfiltered stereo 3D contour map of the 1964 USGS Bouguer gravity anomaly map of the U.S. (see Gay, 1971, for discussion of the benefits of 3D stereo contour maps for interpretation - now an established procedure in some fields). A superposed circle (dashed line) of 2100 km diameter shows the close approximation of the gravity low to a circle. The center of the circle lies near Pioche, Nevada, at latitude 38º 15' N, longitude 114º 05' W. There is only ±4% variation in the lengths of radii A through L from the circle as I show it. Using the criterion of Pike (1977), the ratio between inscribed and circumscribed circles would thus be 0.85, an indication of a very high degree of circularity that is typical of impacts rather than of volcanic calderas, and certainly much higher than the ratio for a random collection of unrelated structural or topographic features.

In Fig. 2, I show small-scale low-passed contours of the topography and Bouguer gravity of the western United States first constructed manually by the author in 1976 and upgraded in 2004 by computer techniques. The similarity of the highs and lows on these two maps is remarkable. The circular form of the topography is also striking and will come as a surprise to many people who regard the high topography of the western United States as having an overall north-south trend

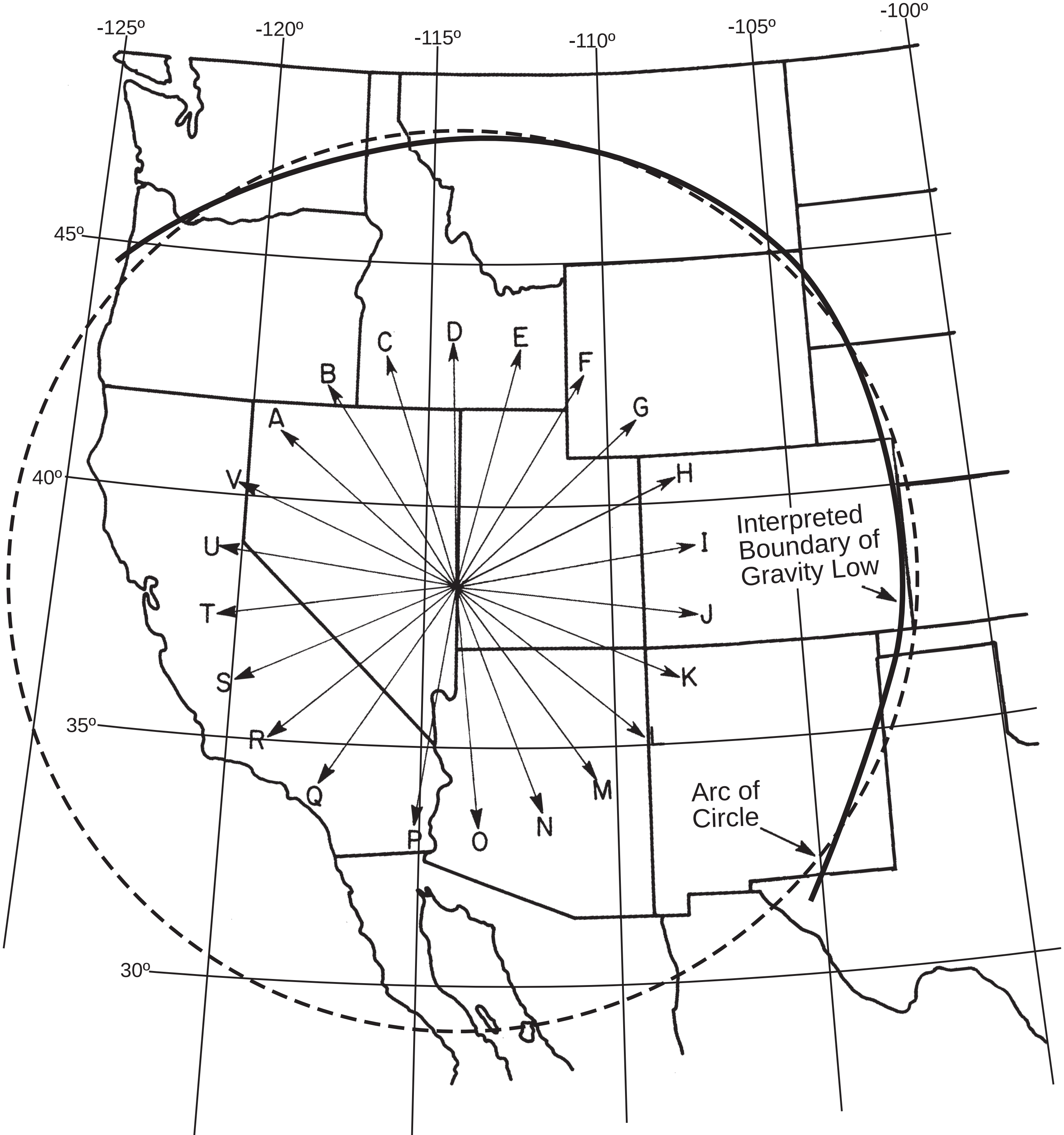

Fig. 1. The heavy line shows the position of the outer boundary of the Western U.S. Gravity Low as interpreted from an unfiltered stereo 3D version (AGI, 1968) of the Gravity Map of the U.S. (Woollard, 1964).

parallel to the Rocky Mountains and the Cordillera. The similarity of regional Bouguer gravity anomalies and topography is a well-known phenomenon and has been discussed by many authors (Wollard, 1962; Watts and Daly, 1981, among others).

In Figure 3 and 4 I show larger-scale figures of the Bouguer gravity and terrain maps with the state boundaries superimposed. These two maps may be used for comparing the two data sets to each other and with the suite of maps that follows.

In Fig. 5 are shown the gravity profiles along radii A through L appearing in Figure 1. All profiles show the steep gradient near the rim, including the averaged profile at the bottom. The averaged profile also shows a gravity high centered at 400 km from the center which would constitute a ring in plan view. Many localized gravity anomalies are apparent in the unfiltered profiles, but there are also large individual highs and lows on the filtered profiles shown. One of the larger lows occurs in the SE part of the Western U.S. Gravity Low and is probably a manifestation of a thickened infilled section of sedimentary rock under the volcanic San Juan Mountains, the site of the lowest Bouguer gravity values in the U.S. On the western side of the Western U.S. gravity low there is a strong gravity gradient corresponding to the west flank of the Sierra Nevada mountain range in California (Figs. 2a and 2b). Here, topographic elevations drop from 14,000 ft on the crest of the range to surface elevations near sea level in the San Joaquin valley, a >20,000 ft deep trench filled with unconsolidated sediments and sedimentary rock. The gravity low corresponding to the crest of the Sierra Nevada range is undoubtedly due to this significant thickness of sedimentary rock that was overridden by the eastward-directed thrusting of the Sierra Nevada batholith by the westward movement of the North American continent in Cretaceous (?) time. This "localized" gravity feature truncates the Western U.S. Gravity Low, so that its westernmost 15% is not visible on the gravity map. The projected western boundary of the Western U.S. Gravity Low occurs farther west in the Pacific Ocean off California (Fig. 1). Another large

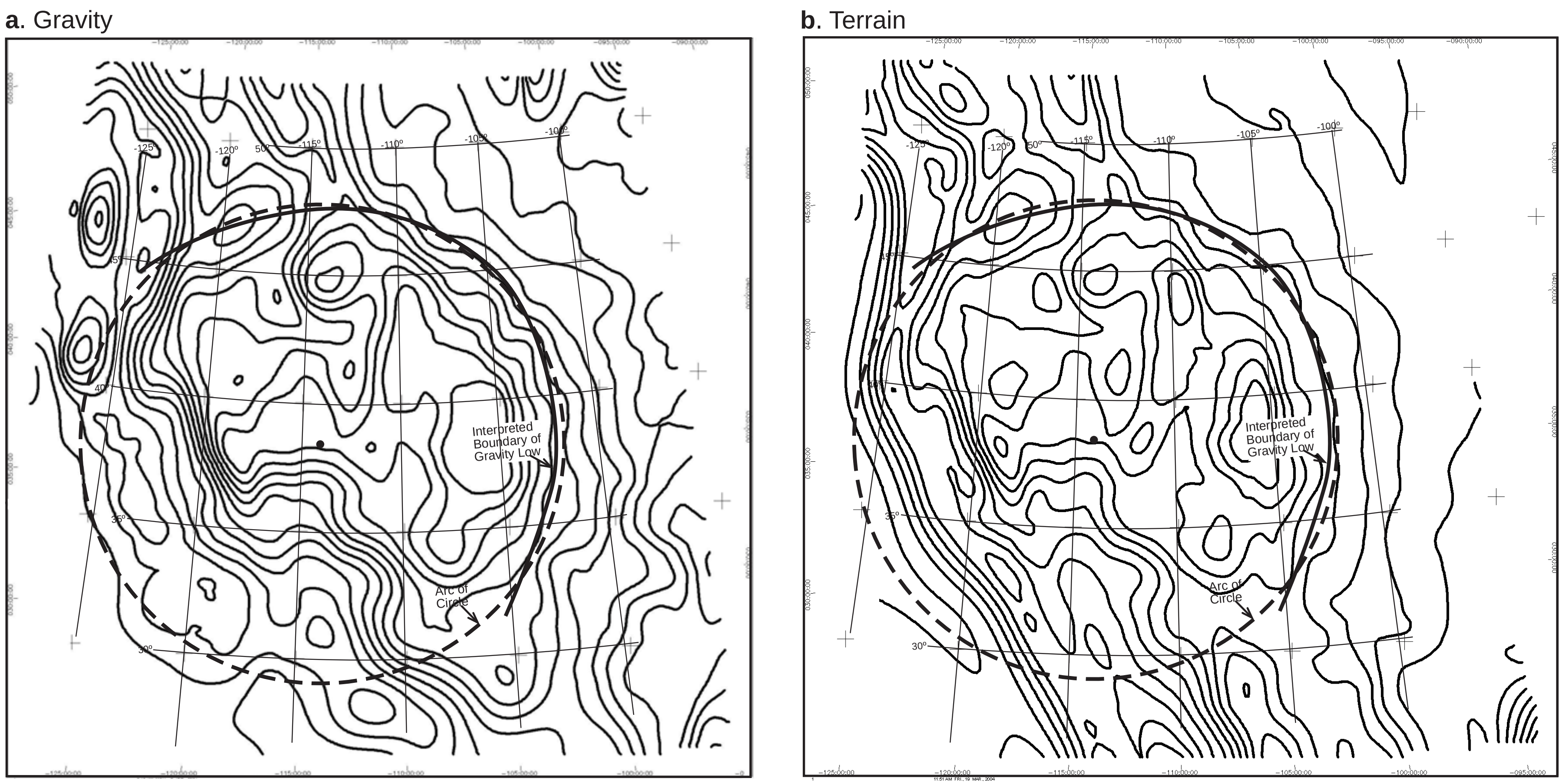

Fig. 2 Smoothed versions of the Bouguer gravity and terrain maps of the western U.S. with the interpreted circular outline superimposed. Contour interval = 200 mgal for gravity, 1000 ft. for terrain.

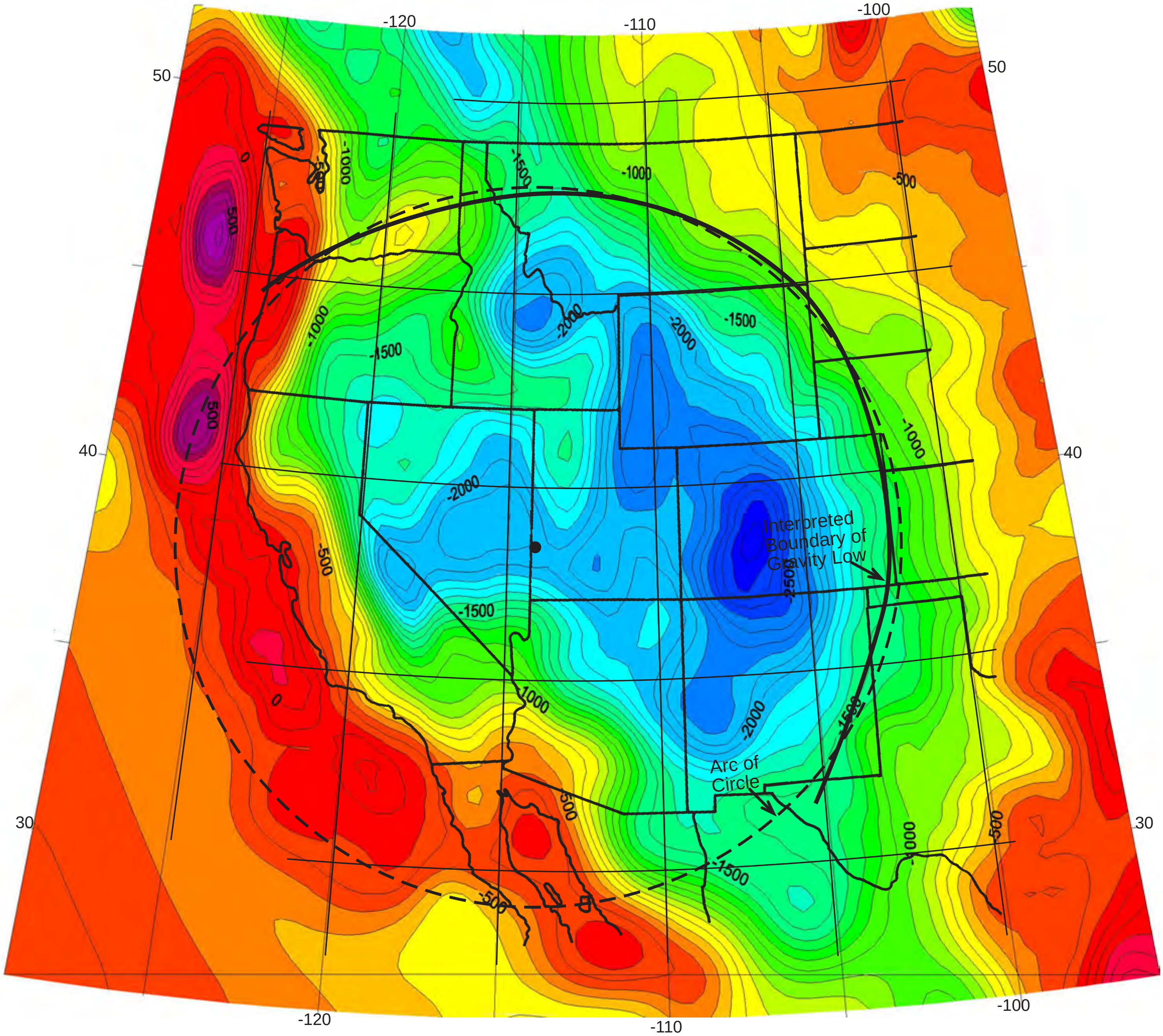

Fig. 3. Smoothed Bouguer gravity map of western U.S. Contour interval 100 mg. Data from NOAA-NGDC Gravity CD, 1999.

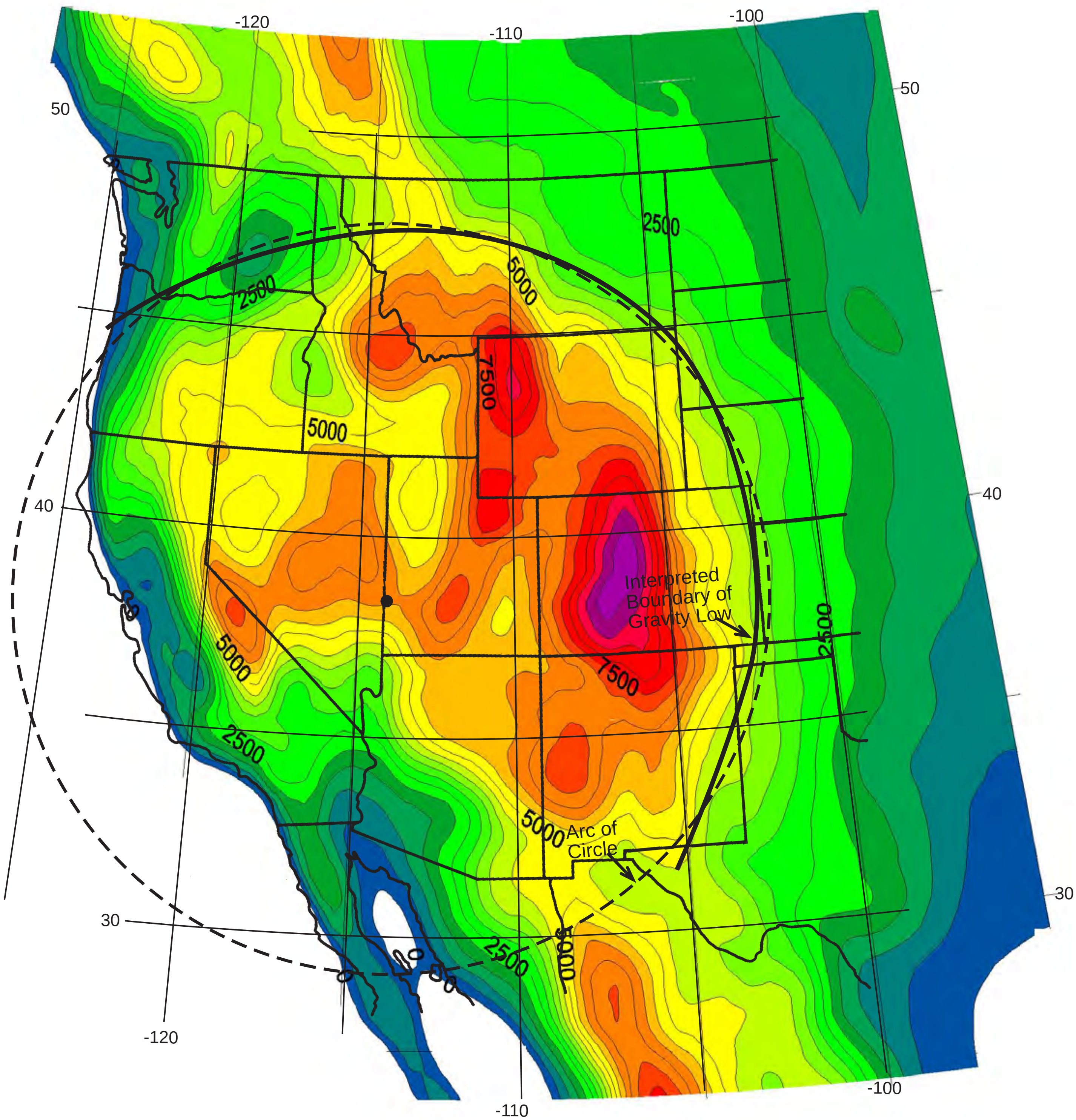

Fig. 4. Smoothed terrain map of western U.S. Contour interval 500 ft. Data from NOAA-NGDC Terrain Base CD, 1994.

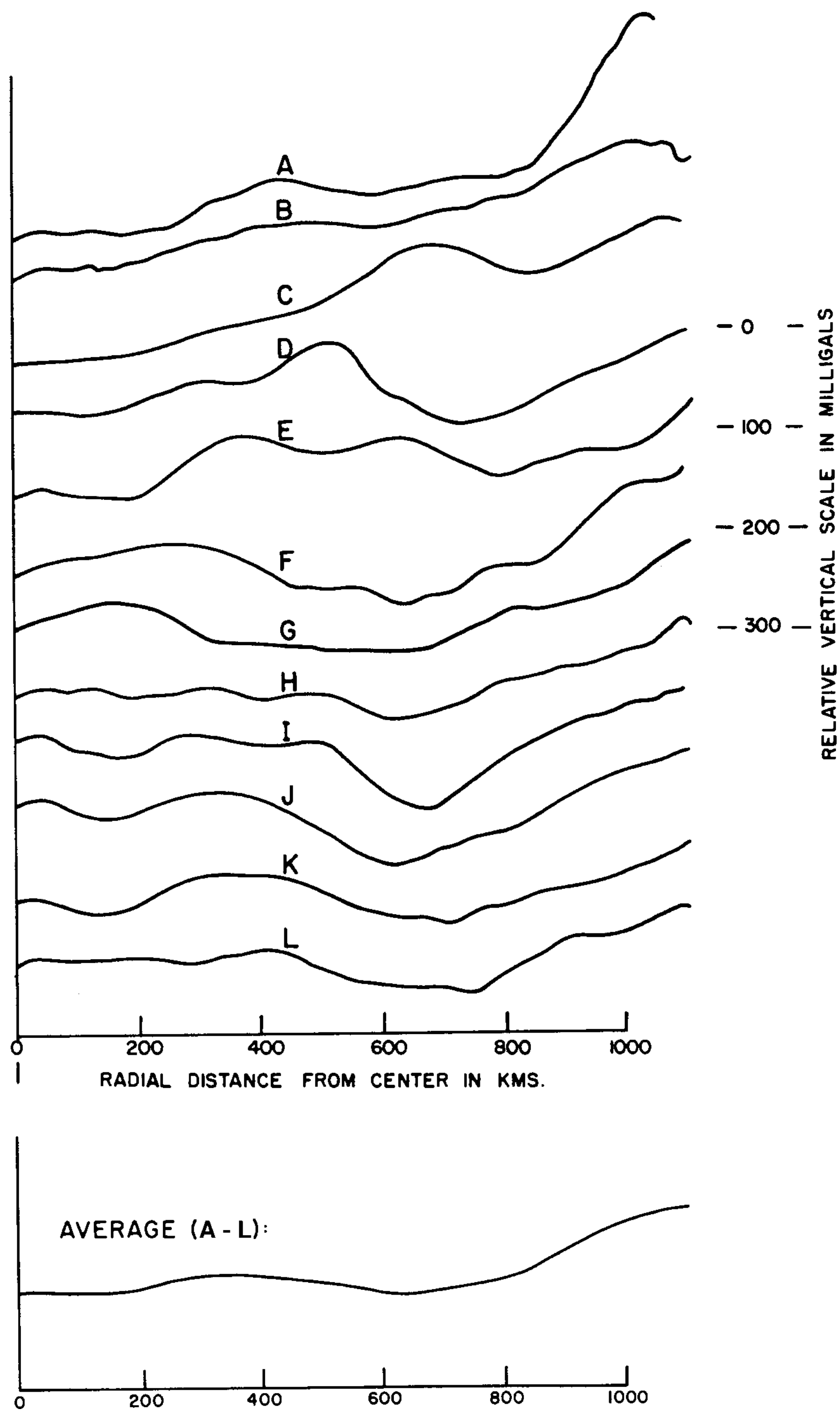

Fig. 5. Smoothed hand-drawn radial profiles across western U.S. Gravity Low (10 pt. running average, points approx. 15 km apart).

"bite" is absent from the Western U.S. Gravity Low and the topographic map in SW Arizona. Both these features may be localized, i.e. near-surface, crustal features, unrelated to a broader source at depth, although the free air gravity map (Figure 8), indicates they may also reflect mantle properties.

A rather spectacular representation of the Western U.S. Gravity Low is illustrated in Figure 6. This is a segment of the Tectonic Map of North American (King, 1969) that shows how the tectonically disturbed Cordilleran belt has double its average width in the Western U.S. compared to its width immediately to the north and south in Canada and Mexico. The disturbed belts extend east and west to occupy nearly the total area of the Western U.S. Gravity Low/Topographic High. Also note the bulge in the Oregon-California coastline corresponding to the gravity low.

In Figure 7, I show a related correlation. Here, sedimentary basins that lie within 100-300 km of the northern, eastern, and southern boundaries of the Western U.S. Gravity Low in New Mexico, Colorado, Wyoming, Montana, and Oregon are plotted from Bayley & Muehlberger, 1968. The basins all lie parallel or subparallel to the boundary and concentric to the supposed central uplift and not parallel to the northwest trending Cordillera. The ones in New Mexico trend northeast, the one in Colorado is north-south, those in Wyoming and Montana run northwest, and the one in Oregon is nearly east-west. These are all foreland basins ascribed to compression and uplift of adjacent mountain ranges by thrusting, but they cannot all be explained by the east-northeast directed Laramide compression generally accepted for this region. They must parallel the boundary of the Western U.S. Gravity Low because they are evidently following the concentric faulting arising from the impact. Of interest, also, is that two major U.S. sedimentary basins lie just outside of, and are peripheral, to the U.S. Gravity Low and share common linear elements: the Williston Basin in N.and S. Dakota and the Permian Basin in New Mexico and Texas.

To summarize the material I have presented thus far, the topography of the western U.S. is dominated by a regional high that is circular in form, resulting in a circular Bouguer gravity low that

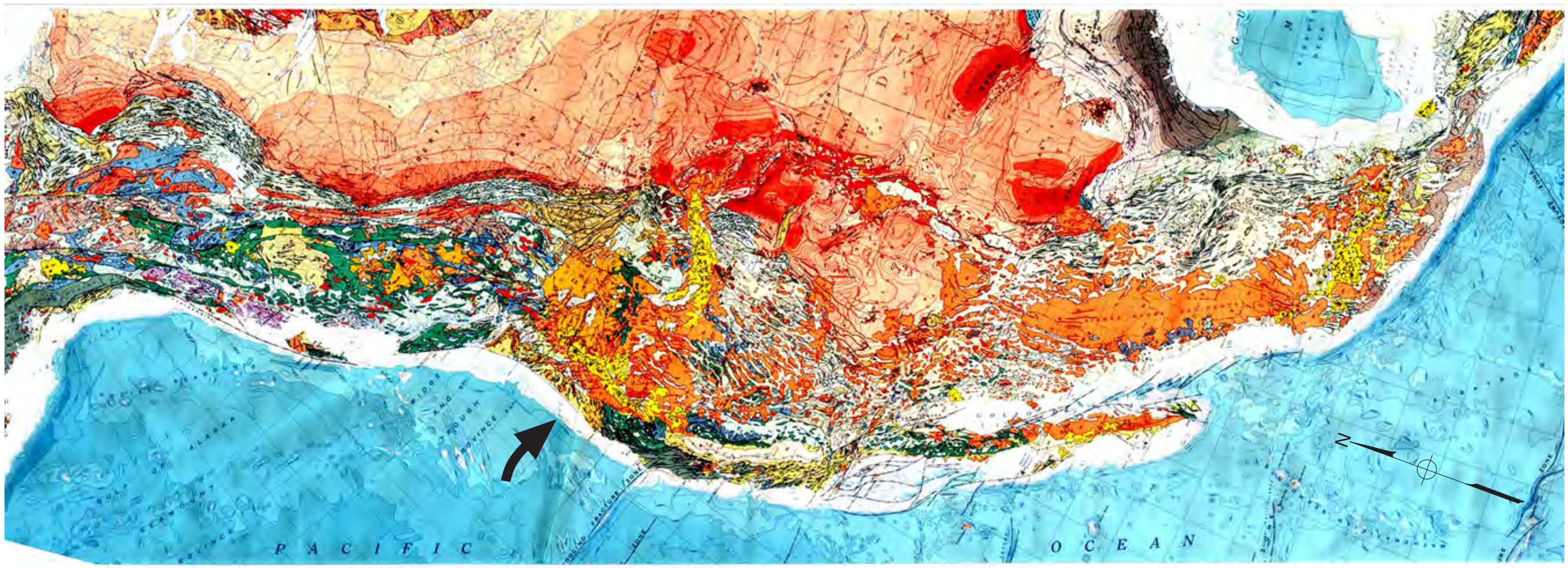

Fig. 6. The Tectonic Map of North America (King, 1969) outlines in a most convincing manner the circular nature of the crustal or mantle feature corresponding to the Western U.S. Gravity Low (arrow). Note the bulge in the Oregon/California coastline around this structure. Also, note the doubling in the width of the U.S. Cordillera over that in Canada (bottom) and Mexico (top).

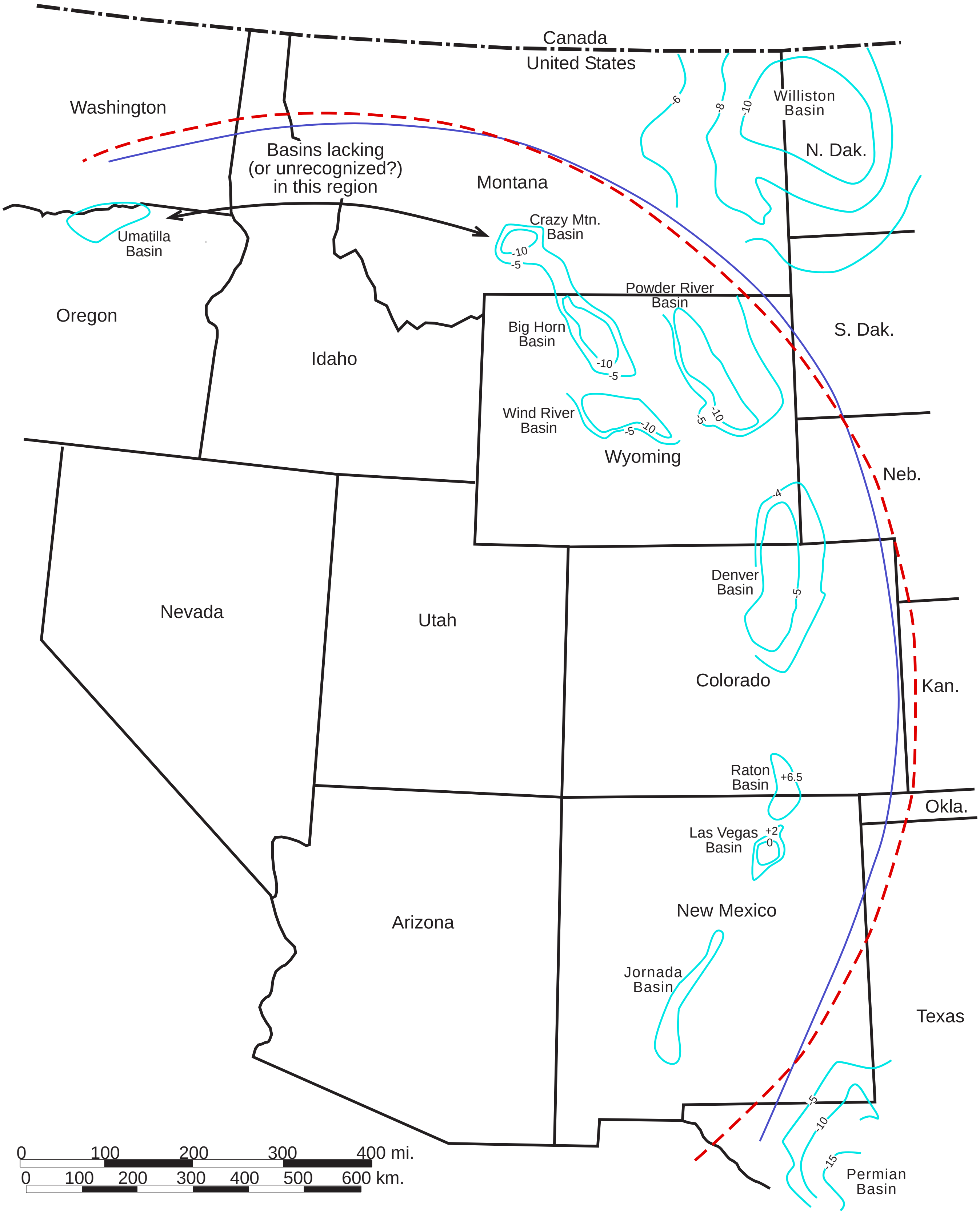

Fig. 7. Western U.S. sedimentary basins that lie 100-300 km within the boundary of the GravityLow/Topographic high are parallel to the boundary. Numbers are structure contour values in thousands of feet sub-sealevel. Williston & Permian Basins are located jut outside the boundary and are peripheral to it.

can be fitted, with high precision, to a 2100 km diameter circle. Several aspects of regional geology have been shown to conform to, or be affected by, this circular feature. I propose that this is the mantle scar of an ancient planetesimal infall comparable to those that impacted the Moon, Mars, and Mercury at approximately 3.9 Ga. bp. The North American plate would have moved over this mantle feature in the last drifting episode that separated the continents lying on opposite sides of the present-day mid-Atlantic Ridge. This would explain the uplift of the western U.S. that took place beginning in late Triassic time, perhaps deriving its rise of about 2 km average across the 2100 km diameter (a ratio of 1 in 1000) due to its location over a slightly denser substrate. Some have called this the uplift of the Colorado Plateau, but according to Shakel (1975) it involved all of the western U.S. Another explanation for the high topography here is high upper mantle temperatures (Kane and Godson, 1989, and Kaban and Mooney, 2001), but this could also be a result of the mantle impact scar. On a related subject, what are the changes in Earth's orbit about the Sun and in Earth's rotation rate that might have taken place due to such a large impact and similar impacts that could have occurred at this time?

ANOMALOUS PROPERTIES OF THE CRUST AND MANTLE OF THE WESTERN U.S.

To facilitate the work of future reviewers, many of whom are specialists in only certain aspects of geology and geophysics, I will present data in this section from many workers at many institutions that document the anomalous nature of the mantle (and crust?) under the western U.S. Whereas this data does not <u>prove</u> that the Western U.S. Gravity Low/Topographic High represents the mantle scar of a mare-type impact, it certainly lends support to that possibility. In 1964, Thompson and Talwani stated: "In the last few years, seismic refraction evidence has accumulated which indicates that the crust and upper mantle in the western United States have a structure different from what had been hitherto considered normal continental structure. Instead of a crust approximately 35 km thick with seismic velocities from about 6.0 to 7.2 km per second, overlying a mantle of velocity 8.0 to 8.2 km per second, a crust approximately two-thirds the normal thickness has been found overlying a mantle of anomalously low velocity." These conclusions are as valid today as when they were written in 1964, but seismic surveys, heat flow, and other types of studies have expanded considerably in the subsequent 40 years, and much more detail for mapping this feature is available now. I have gathered the latest maps and data of the western U.S. and show them in the following figures. Figure 8: free-air gravity, Figure 9: upper mantle seismic velocities, Figure 10: crustal seismic velocities, Figure 11: crustal thickness, Figure 12: heat flow, Figure 13: deviation of the geoid. A brief discussion of each of these data sets follows.

FREE-AIR GRAVITY

Some geophysicists favor free-air gravity rather than Bouguer gravity for regional studies because Bouguer gravity reflects regional terrain. This fact was partially responsible for the rejection of the earlier paper (Gay, 1969) that I prepared on the Western U.S. Gravity Low/Topo High, as I failed to point this out. However, a 2100 km diameter circular topographic high is every bit as significant geologically as a 2100 km diameter circular gravity anomaly, so the realization that the Western U.S. Gravity low indicated a circular topographic high was a strange argument in favor of an earth mare, not an argument against it, according to some reviewers/detractors.

I here present the free-air gravity anomaly map of the western U.S. (Figure 8) with the superimposed boundary of the Bouguer gravity low/topo high. Comparing Figure 8 to Figures 3 and 4, the Bouguer gravity and topographic maps, it is seen that the free-air gravity values are inverted relative to the Bouguer values. This would indicate higher density subsurface material under the Western U.S. Gravity Low, suggesting an original basaltic infilling for the supposed impact. However, there are differences between the free-air gravity and the Bouguer gravity/topographic maps. The prominent northerly trending free-air gravity high in the northeast corner of Figure 8 that follows the Montana-Dakotas state line corresponds to the Trans-Hudson Orogen (Nelson, 1993) and thus may be of crustal origin. It is not at all apparent in the terrain or Bouguer gravity maps (Figures 3, 4). Additionally, free-air gravity highs in central and northern Montana are also not reflected by the Bouguer gravity or terrain maps. The circularity of the Western U.S. Gravity Low shown in Figures 3 & 4 is not apparent on the free-air gravity map, so the only contribution of the free-air gravity data to this project is the finding that denser mantle materials apparently underlie the Western U.S. Gravity Low rather than lighter ones.

UPPER MANTLE SEISMIC VELOCITY

This map (data courtesy of Walter Mooney, 2004, also published on the Web) shows low upper mantle seismic velocities for the area of the Western U.S. Gravity Low (Figure 9), and it gives an unexpected confirmation of the western and southwestern boundary of the low under the Pacific Ocean, the only data set to do so. There is also good correlation of the eastern and northern boundaries, but some areas in the southeast and the northwest do not show a return to high velocities outside the area of the supposed impact, as they do elsewhere. Someone more familiar with this type of data than I would be able to determine if these latter problems are significant.

CRUSTAL SEISMIC VELOCITY

I include this data set (Figure 10) because it is readily available (also from Mooney, as above), not because I believe it is significant to the problem, because if a crustal plate has moved over the mantle scar of an impact, then that crust's characteristics should be independent of the scar. Nevertheless, this diagram suggests low crustal velocities are coincident with the impact. If this is a real correlation, there may be explanations for it that don't invoke a crust correlative to the underlying scar. For example, the high heat flow in this region may lower the crustal seismic velocities. Secondly, there may be "mixing" of the seismic signal with the low upper mantle

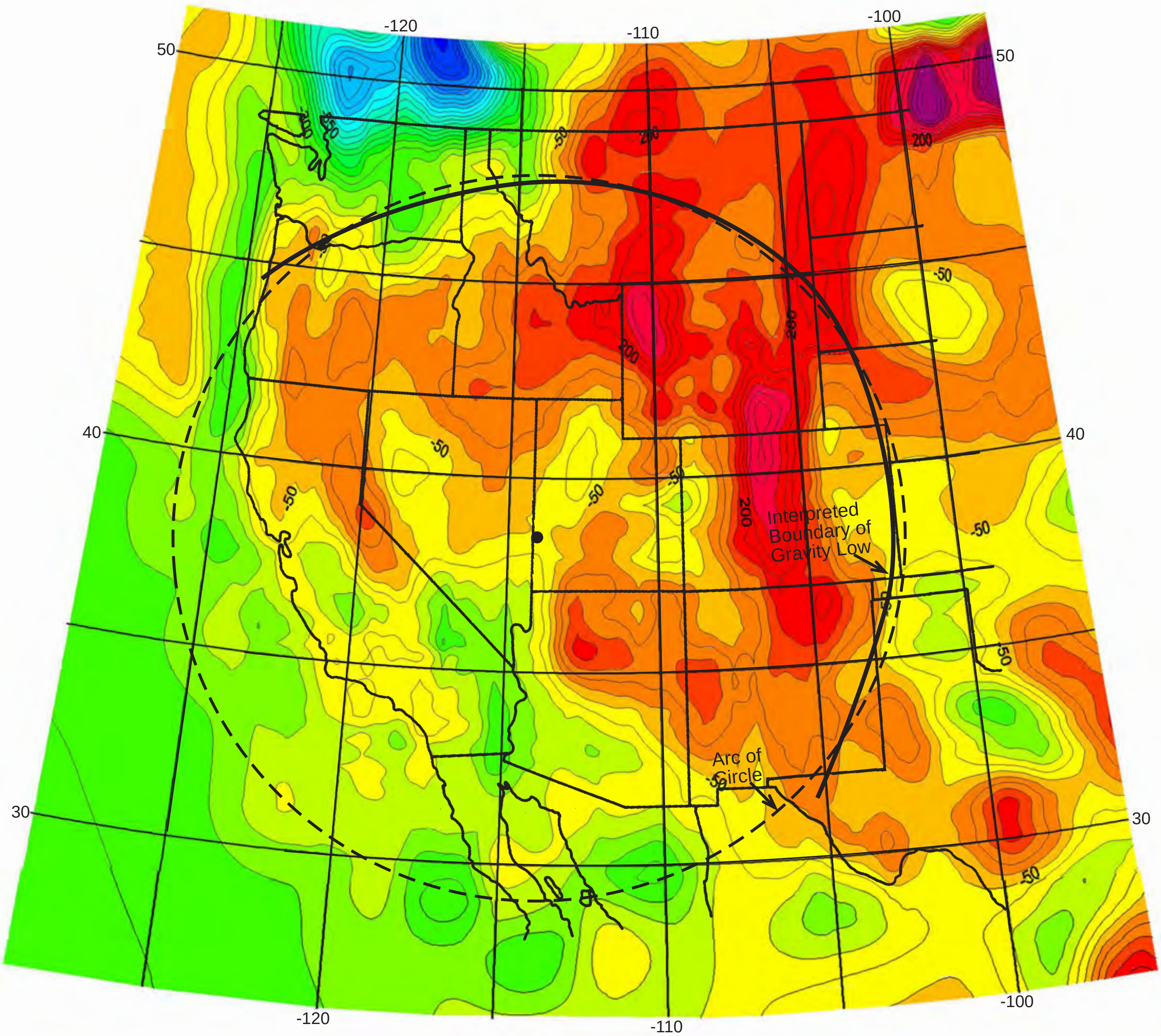

Fig. 8. Smoothed free-air gravity map of western U.S. Contour interval = 25 mg. Data from NOAA-NGDC Gravity CD, 1999.

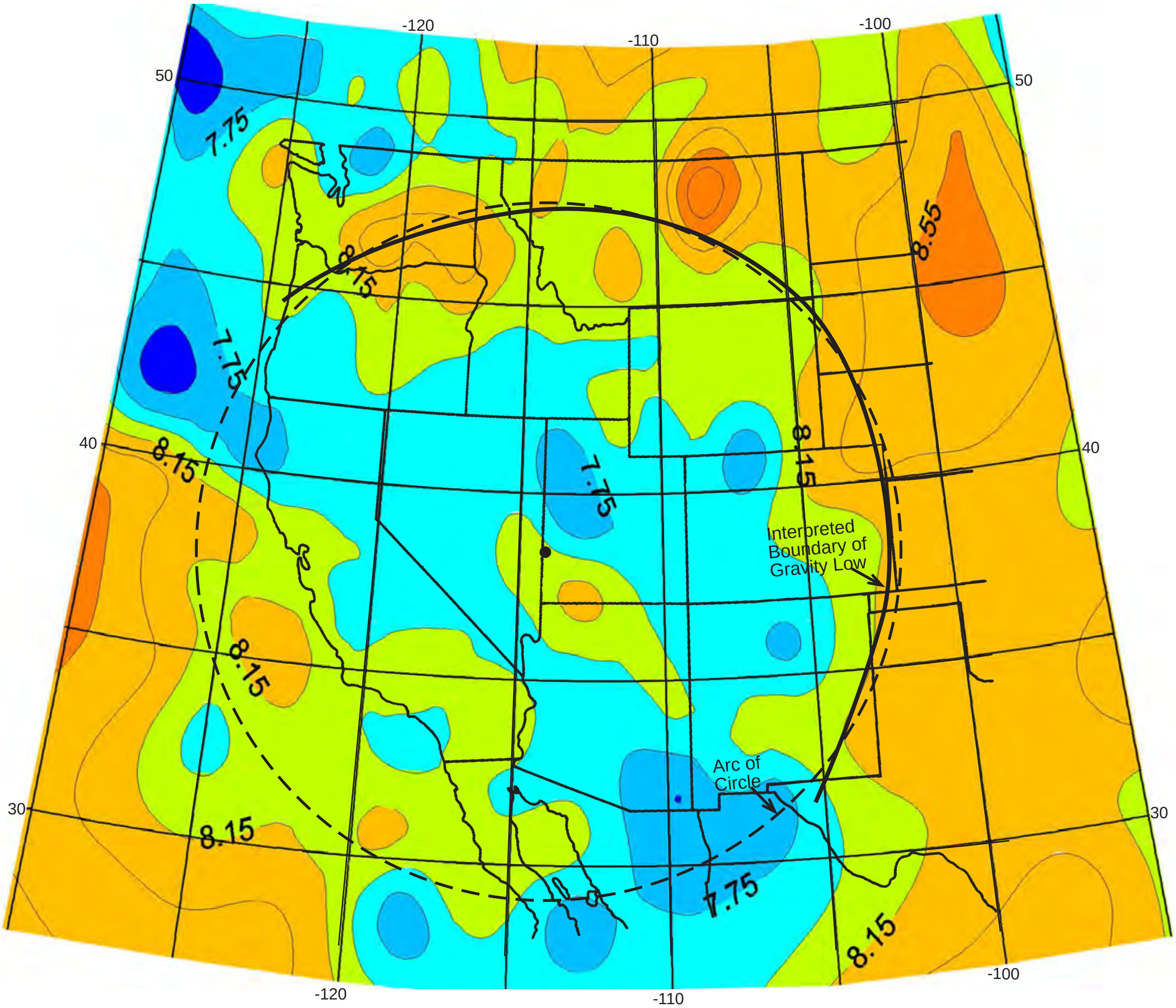

Fig. 9. Upper Mantle p-wave velocity map of western U.S. Contour interval 0.5 km/s. Data courtesy of Walter Mooney, 2004.

velocities underneath. Again, people more qualified on this subject than myself would be required to assess the relevance of this data set to the problem at hand.

CRUSTAL THICKNESS

The thickness of the crust is defined as the depth to the Mohorovicic discontinuity where the seismic velocity suddenly increases below the lower crust-upper mantle boundary. In the western U.S. this velocity change is shallower than elsewhere, thus making the crust here thinner than average (see statement by Thompson and Talwani, 1964, above). In Figure 11 is shown the latest map of crustal thickness, again courtesy of Walter Mooney (pers. comm. 2004). Lower values generally coincide with the interior of the Western U.S. Gravity Low, with higher values outside. However, this map certainly could not be used to confirm or deny the existence of a circular impact structure in this area, due to the sparcity of data points, but it does lend support to the anomalous nature of the crust in the western U.S.

It should be noted that the Mohorovicic discontinuity is higher in the western U.S. (giving us the thinner crust) just as the terrain is higher in this region.

HEAT FLOW VALUES

The high heat flow of the western U.S. is shown by the map in Figure 12, and the high values fall closely within the boundaries of the superimposed impact. It could therefore be concluded that the proposed crater filling is either characterized by 1) high heat generation (more radioactive elements), or 2) higher transmissivity of heat from lower in the mantle. The higher heat values may affect both seismic velocities and electrical resistivity (below), and two papers have cited it as the cause of the higher topography here (Kane & Godson, 1989, and Kaban & Mooney, 2001).

ELECTRICAL RESISTIVITY VALUES

There are insufficient data points to prepare a map of upper mantle electrical resistivities of the western U.S. (or anywhere in the U.S. for that matter), but the few points that are available do

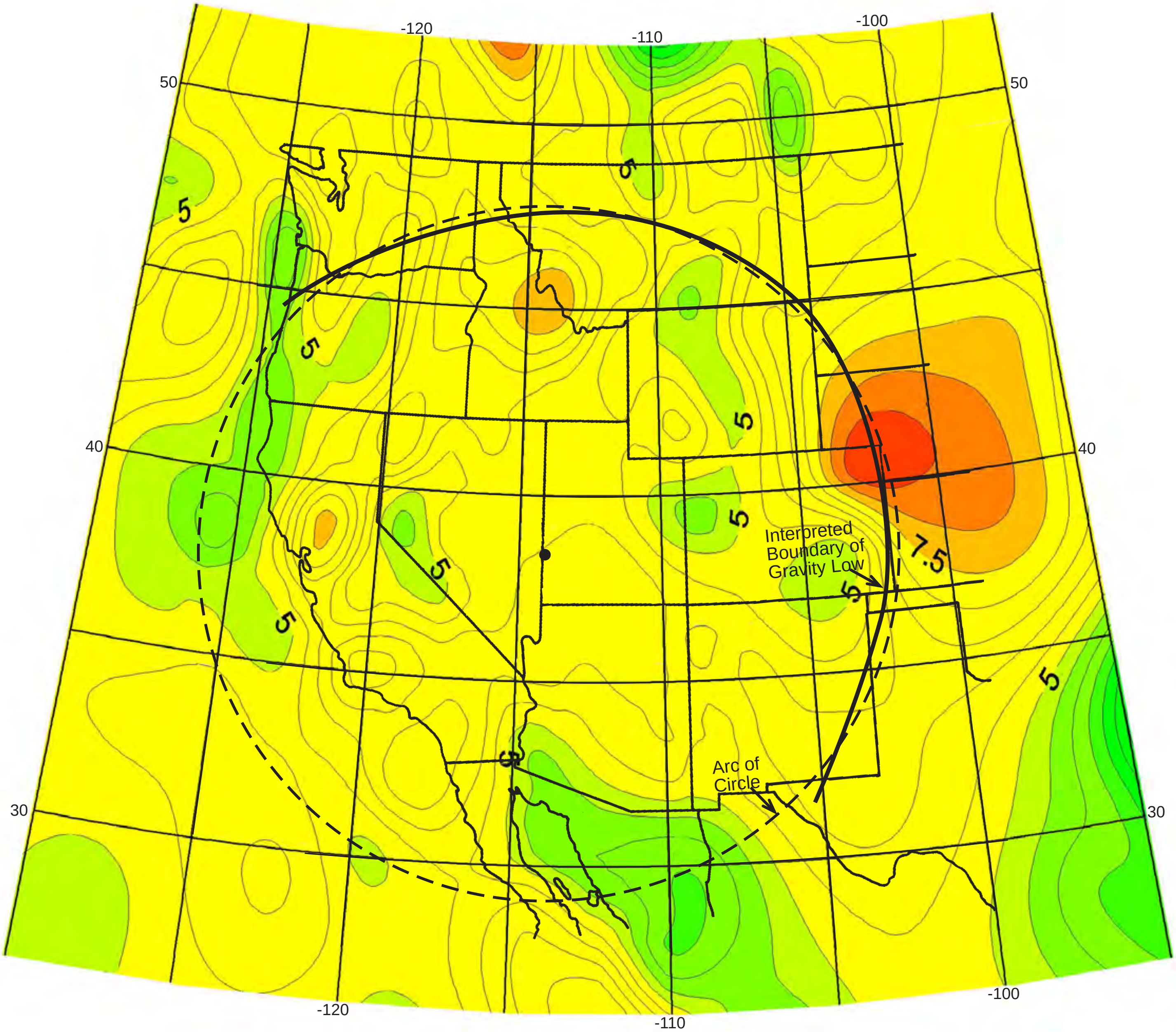

Fig. 10. Crustal p-wave velocity map (w/sedimentary section) of western U.S. Contour interval = 0.5 km/s. Data courtesy of Walter Mooney, 2004.

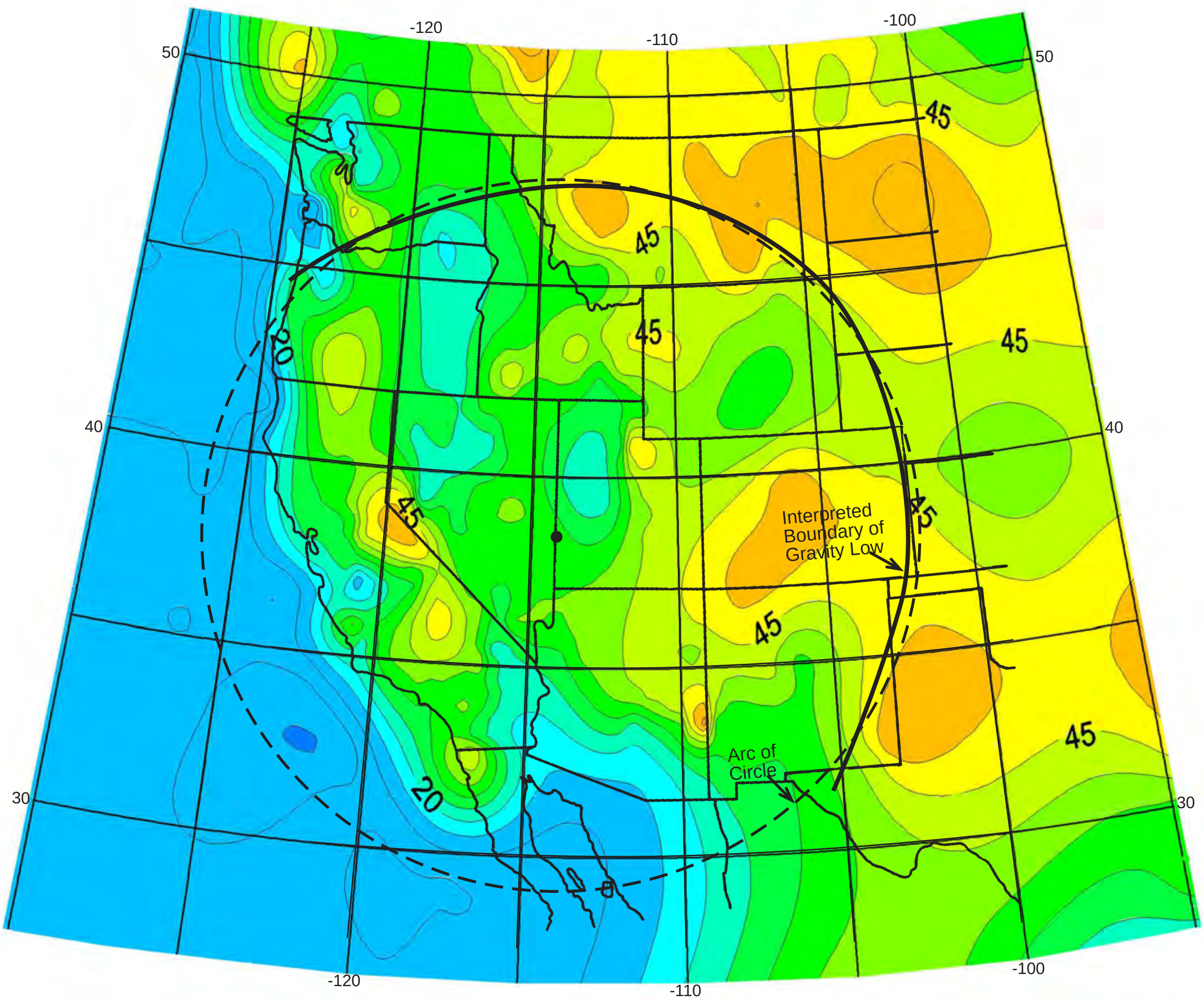

Fig. 11. Crustal thickness map of western U.S. Contour interval = 5 km. Data courtesy of Walter Mooney, 2004.

indicate it is a zone of low resistivity/high conductivity. This follows also from the high heat flow values. One pertinent study carried out in southern Arizona and New Mexico shows a transition from low resistivities within the boundary to high values outside the boundary, the change taking place near Roswell, New Mexico, almost precisely at the location of the boundary shown in the figures (Warren et al, 1969).

GEOID

Bomford (1971) defined the geoid as "...a surface coinciding with mean sea-level in oceans, and lying under the land at the level to which the sea would reach if admitted by small frictionless channels." In their actual construction, geoid maps are based on free-air gravity maps and resemble them. Thus, Figure 13, the map of the geoid in the western U.S. resembles Figure 8, the free-air gravity map. This circular geoid anomaly does not coincide with the Bouguer gravity low/topographic high, being offset from it by about 400 km. Why this is so, I cannot say. However, the high circular topography comprising the proposed impact centered on Pioche, Nevada, is a physical reality. It may be that free-air gravity maps give us a false picture of the Earth's gravity field because the slab of earth beneath the station down to sea level is not corrected for. The Bouguer correction may thus be more valid than we have thought.

SUMMARY

The most prominent feature on the 3D Bouguer gravity map of the United States, (King, 19-69), is the Western U.S. Gravity Low. Careful tracing of the boundary of this low on the unfiltered stereo 3D gravity map shows it to be nearly circular in shape and 2100 km in diameter. Since regional Bouguer gravity values closely mimic regional topography, in reverse fashion, the topography of the western U.S. was plotted and compared to the gravity map and was also found to show the circular shape. The feature is therefore termed the Western U.S. Gravity Low/Topographic High.

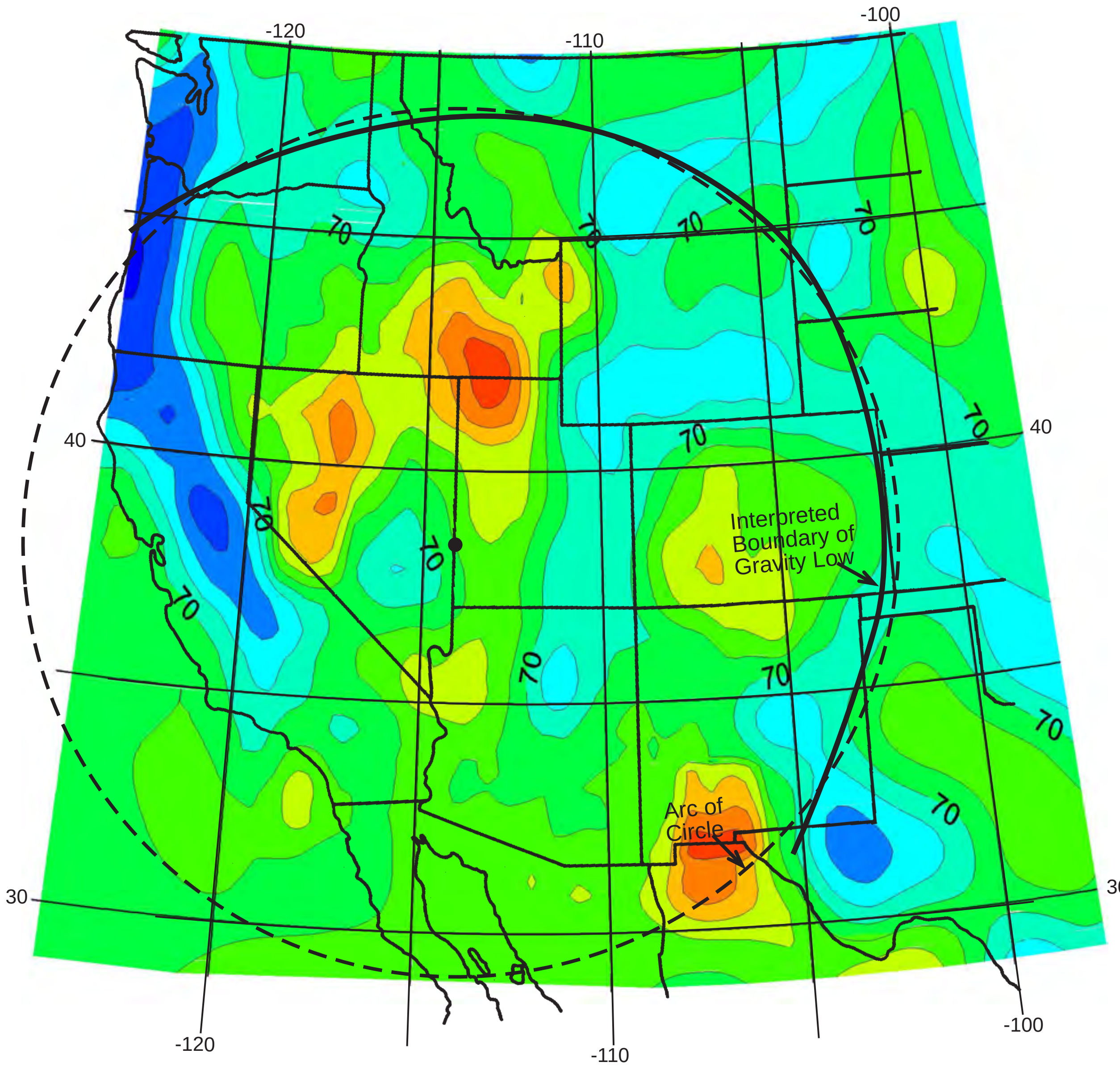

Fig. 12. Heat flow map of western U.S. Contour interval = 10 $m\mathrm{W/m^2}$. Data courtesy of David Blackwell, 2004.

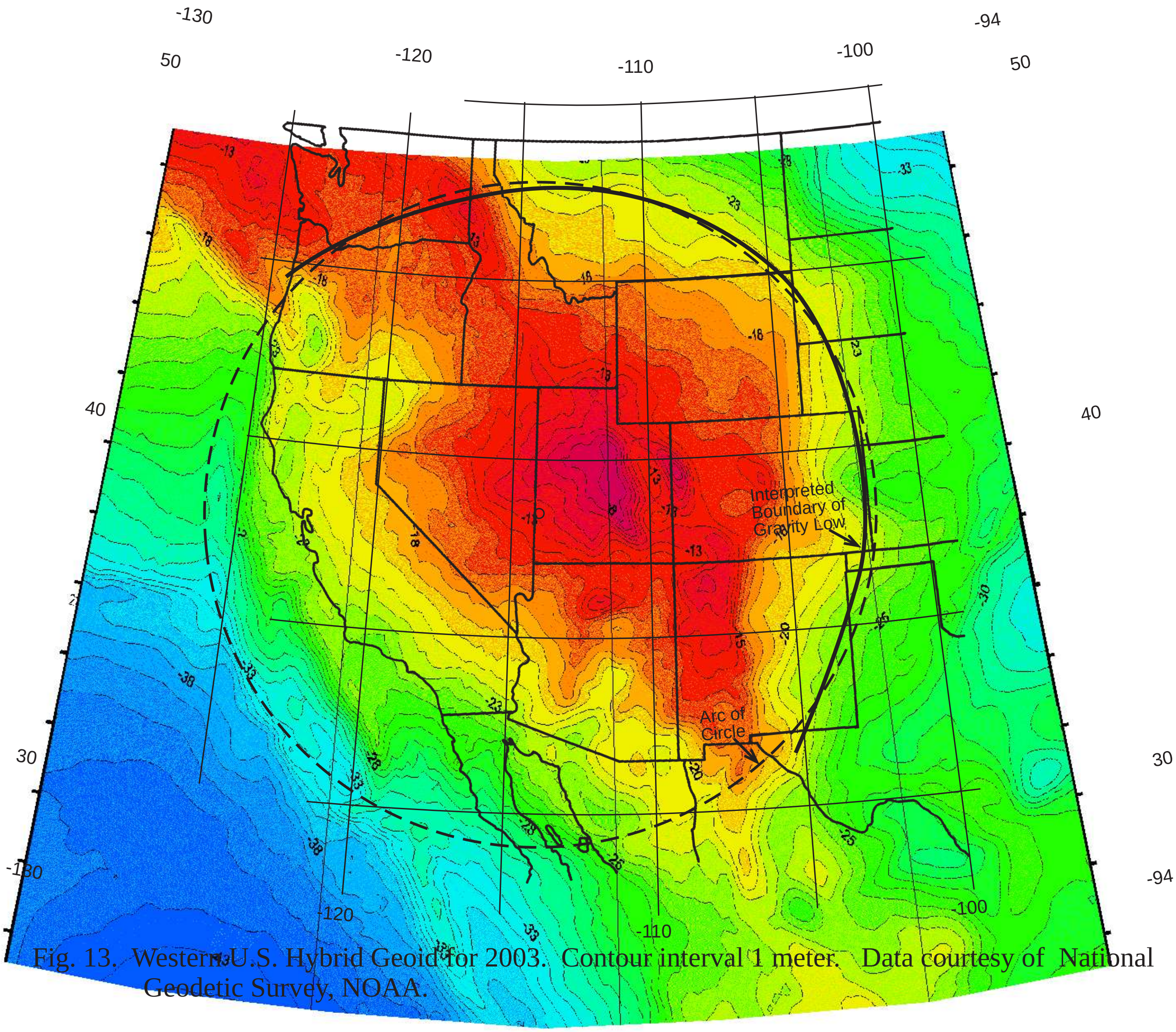

Fig. 13. Western U.S. Hybrid Geoid for 2003. Contour interval 1 meter. Data courtesy of National Geodetic Survey, NOAA.

Circular geologic features of this size and shape are only represented on Earth, the terrestrial planets and some of the solar system moons as craters of late-stage planetesimal infalls. Those on the Moon impacted at approximately 3.9 Ga. Depth of a 2100 km diameter crater is estimated at 600 km or more, so that the crater and its infilled materials extends deep into the upper mantle, far below the bottom of continental crustal plates. Consequently, several data sets have been looked at to examine the possibility of anomalous upper mantle characteristics coincident with the proposed impact. Upper mantle seismic velocity, crustal thickness, heat flow, and electrical resistivity data all support, to a degree, the anomalous nature of the mantle in the Western U.S.

However, my interpretations and explanations for the many details of the nature of the U.S. Gravity Low/Topographic High may not be totally correct or may be incomplete, but the existence of this feature and its circularity are indisputable, and thus its origin as a planetesimal infall must be correct.

Acknowledgements

The author wishes to thank Walter Mooney and David Blackwell for providing their detailed digital seismic and heat flow data compilations for the western U.S. to the author. He also thanks Paul Lowman for his comments on the paper at various stages in its preparation and for providing a number of salient facts. Most importantly, he thanks Ben Opfermann for the tremendous amount of computer manipulation over a period of many months on data from many sources that resulted in the illustrations herein, and Anna Mariea Gay (deceased 2013) for the typing of many manuscripts.

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Remarks on

"THE WESTERN U.S. BOUGUER GRAVITY LOW/TOPOGRAPHIC HIGH: THE RESULT OF AN EARLY PLANETESIMAL INFALL?"

S. Parker Gay, Jr., April 19, 2017

The presence of a 2100 km (1300 mile) diameter gravity low covering almost the entire western U.S. was pointed out in a paper I submitted to a prominent scientific journal in 1969. I determined that this gravity low was quite circular in nature, and that the only geological features of such size and shape are the late planetesimal impacts visible on the moon and on the sun's inner planets. Therefore I concluded that this feature must also be a late planetesimal impact. The paper was reviewed by several prominent geologists of that time (1969), but was rejected based on conflicting arguments that they presented. I did not resubmit the paper to any other journal then because I concluded that the paper would probably have been sent again mostly to these same reviewers.

The paper thus lay dormant in my files for thirty four years until it almost faded from my memory, but when I did recall it occasionally , I was greatly perturbed, because I long ago concluded that my geological arguments for an impact were much more compelling that the arguments against it. So in 2003, I undertook a rewrite of the article to rebut some of the 1969 reviews and also to include new material that had come to light in the intervening years, including a very good 1969 geological map of the western U.S. (see figure 6).

But this time an unexpected circumstance again occurred. I had prepared this paper for submittal to the 17th Volume Basement Tectonic Conference, but had a disagreement with the reviewer/program chairman on a different paper, so decided that it would not be worthwhile to submit the second paper (this one) to the conference. Thus, this paper lay idle 13 more years (since 2004) further delaying publication of the evidence for this important and unique geological feature. Meanwhile, on-line (Internet) publishing has become all the rage, and although I greatly prefer publishing in hard copy, this on-line copy will have to suffice until some forward-looking editor will publish this old paper, as is, or after another author modifies it with new material. In reading this comment, please keep in mind that this paper was written/rewritten in 2003 and has not been updated since. However, I have somewhat kept track of the subsequent literature and have not run across any new work that would substantially modify the earlier conclusions.

On a personal note, my longevity (87 in 2017) has allowed me to pursue this subject after many of my detractors have passed away or are no longer active . I must say that I am grateful that Mother Nature has been very kind to me in this regard.

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