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GRAVITY AND AEROMAGNETIC ANOMALIES OF SOUTHEASTERN ARIZONA*

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INTRODUCTION

Southeastern Arizona is in the Mexican Highlands physiographic sub-province of the Basin and Range province (fig. 1). The highest elevations between the Pacific Ocean and the Great Plains at the latitude of southeastern Arizona occur in southeastern Arizona, with the axis of the elevation high at the Arizona-New Mexico border.

Drewes (1978) has pointed out the significance of southeastern Arizona in the regional tectonic framework of North America. It lies in an area with strong northwest trends in Precambrian and younger rocks. Major Precambrian and Mesozoic tectonic boundaries have been defined in the area. Drewes (1978) also suggested that the so-called Texas lineament was a consequence of these boundaries and not produced by a strike-slip feature.

In a topographic sense half of the area is made up of valleys. However, wide pediments in these valleys, covered by alluvium up to 1000 m thick, may be structurally related to the mountain ranges. The grabens between these pediments constitute only a small fraction of the total valley surface area. This north-south structure reflects late Cenozoic Basin and Range tecton ism.

Information on the depth and composition of the basins are dependent on 76 holes drilled for hydrocarbons and 14 holes drilled for stratigraphic information in southeastern Arizona. Only about 25 are bottomed in what is considered to be non-Cenozoic consolidated material and these are located over pediments (Aiken and Sumner, 1974). A deep test hole drilled by Exxon in Picacho basin northwest of Tucson extends to the Precambrian basement at 3103 m but is outside the area of this study (Conley, 1974).

Considerable gravity and magnetic data have been gathered in southeastern Arizona as part of larger programs or for specific projects in the area. Results are summarized in several maps: Bouguer gravity (West and Sumner, 1973), residual Bouguer gravity (Aiken, 1975), free-air gravity (Aiken and others, 1976) and residual aeromagnetic (Sauck and Sumner, 1970) anomaly maps of Arizona. General analyses of these basic data sets for southeastern Arizona have been made by Sauck (1972), West (1972), Aiken (1976), Sumner and others (1976) and Aiken (1978); for the area in particular by Aiken and Sumner (1974); and for selected areas by Eaton (1972), Spangler (1969), Bittson (1976), Lynch (1972) and Robinson (1975). In this discussion the results of Aiken and Sumner (1974) and Aiken (1976) will be used extensively.

Geophysical data other than gravity and aeromagnetic coverage is very sparse. Ongoing studies of heat flow (M. Reiter, pers. commun.), electrical surveys (J. Hermance, pers. commun.) and crustal seismic surveys (G. R. Keller, pers. commun.) will soon provide the needed information to better analyze the crust and mantle of southeastern Arizona. Existing data can aid in indicating the general character of the crust and mantle in the region.

Interpretation of some of the existing geophysical data appears contradictory. Crustal thickness is estimated by Pakiser and Zietz (1965) to increase from 35 to 40 km west to east across the area. Warren (1969), however, interpreted ambiguous changes in thickness of the crust. A possible change in Pn velocity from 7.8 to 8.1 km/sec west to east (Herrin and Tagger, 1962) also occurs and could contribute to errors generated in the computation of crustal thicknesses.

Hermance and Pedersen (1976) fit the geomagnetic variation data of Schmucker (1964) with vertical prisms of varying resistivities instead of horizontal layering. In this model southeastern Arizona and southwestern New Mexico have higher resistivities than west of Tucson and in the Rio Grande rift.

Heat-flow data are sparse, and completely corrected data even more rare. At present there is only one heat-flow value between Tucson and New Mexico, in the Dragoon Mountains, a surprisingly low 1.5 HFU (Warren and others, 1969). Just east of the New Mexico line, values of 1.2 to 2.2 HFU are juxtaposed (Reiter and others, 1973). If the 2.2 HFU value adjacent to the 1.2 HFU values is really aberrant, then southeastern Arizona and southwestern New Mexico have relatively low heat flow. To the south, in northern Chihuahua and Sonora, heat-flow values are also very low (1.2 HFU, fully corrected; D. Smith, pers. commun.).

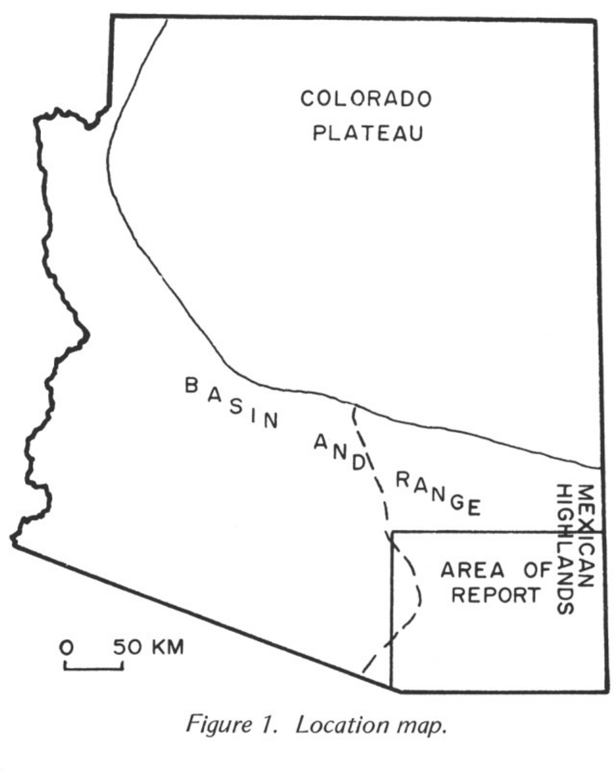

Figure 1. Location map.

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Gravity and aeromagnetic data provide a basis for studying the shallow and deep structure of southeastern Arizona as reflected in the lithologic densities and magnetic susceptibilities. The two data sets will be used to analyze the details of the Basin and Range structure of the area.

GRAVITY AND AEROMAGNETIC ANOMALIES OF SOUTHEASTERN ARIZONA

The Bouguer gravity anomaly map (fig. 2) utilizes data similar to that shown in the Bouguer gravity anomaly map of West and Sumner (1973). Approximately 4000 gravity stations are included. Corrections have been made for terrain between 7 and 167 km from the stations. Except for stations on mountain peaks, with elevations of at least 1500 m above the average elevation of the surrounding area, nearby (less than 7 km) terrain does not significantly effect the interpretations discussed herein.

The aeromagnetic data is taken from Sauck and Sumner (1970) (fig. 3). There are three types of magnetic data included in the area of interest. The data flown by Sauck and Sumner (1970) has two flight levels (2730 m, areas 1 and 3; 3333 m, area 2) and two north-south flight line intervals (5 km, areas 2 and 3; 1.6 km, area 1). In the aeromagnetic map of southeastern Arizona (fig. 4), the slight change in the contours between areas of different flight elevation has been smoothed for the purposes of this report.

Amplitudes of observed anomalies in southeastern Arizona are too large to be due only to topography (Aiken and Sumner, 1974). The topographic effect in aeromagnetic surveying is a function of the air-topography interface (Marsh, 1971). In southeastern Arizona high-altitude aeromagnetic surveys should reflect both the air-topography interface and the geophysical basement topography if the valley fill has no magnetic effect. If the valley-fill material consists of magnetic sediments or

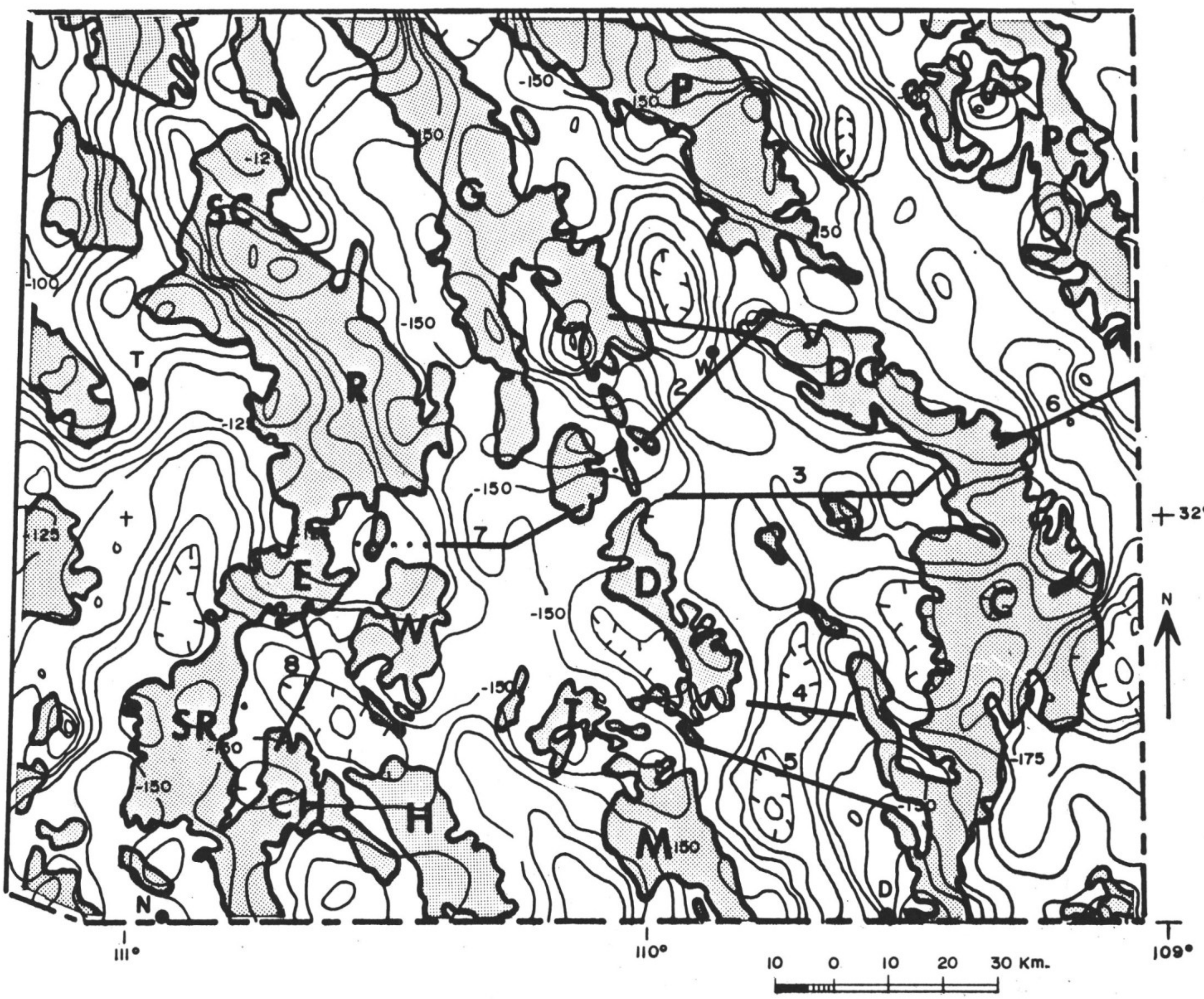


Figure 2. Bouguer gravity anomaly map. Contour interval 5 milligals. Areas of non-valley fill are stippled. Lines 1-8 are gravity model profiles. Dots with T, N, D, W indicate Tucson, Nogales, Douglas and Willcox. Names of mountain ranges are indicated by large letters: SC, Santa Catalina; R, Rincon; E, Empire; W, Whetstone; SR, Santa Rita; CH, Canelo Hills; H, Huachuca; G, Galiuro; D, Dragoon; M, Mule, P, Pinaleno; DC, Dos Cabezas; C, Chiricahua; PC, Peloncillo. Geology from Wilson and others (1969).

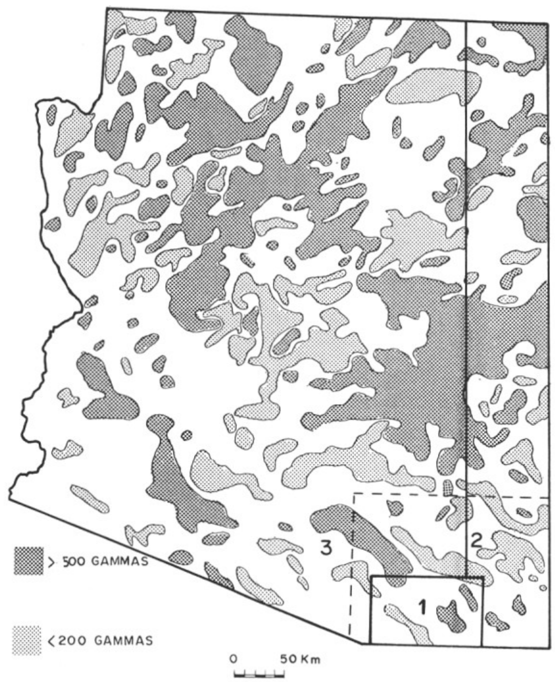


Figure 3. Generalized residual aeromagnetic map of Arizona. Area of report is enclosed by dashed lines. Areas 1 and 3 have 2997 m constant barometric flight elevations; area 2, 3333 m. The line spacing in areas 1 and 2 is 5 km; area 1, 1.6 km (modified from Sauck and Sumner, 1970).

volcanic rocks, magnetic anomalies may be affected, depending on the total thickness and lateral extent of the material. Because of the 5 km line spacing, high flight elevation, and magnetic susceptibility of typical rock types found, the first few kilometers of the upper crust do not strongly effect anomalies. Unlike the gravity anomalies which appear to emphasize the shallow horst and graben structure, the aeromagnetic map, although also effected by shallow structures, is dominated by the effects of deeper sources in the crust.

FREEAIR GRAVITY ANOMALIES

An interesting relationship exists between free-air gravity anomalies and the mountain ranges and valleys of southeastern Arizona. Free-air gravity values on exposed bedrock are almost always positive (fig. 5); those in valley-fill are negative (Aiken and Sumner, 1974). The zero free-air gravity contour to a very close degree maps exposed bedrock. This relationship was also subsequently reported by Robinson (1975) to exist within the lateral resolution of the station spacing (333 m) in Aravaipa Valley between the Galiuro and Penaleno mountains. The only significant departure from this relationship in the area of interest occurs between the Tombstone Hills and the Dragoon Mountains, where positive free-air values extend into a basin. Negative free-air values have not been found on bedrock.

West of the Santa Catalina-Santa Rita mountains the free-air zero contour occurs mostly on bedrock and not at the bedrock-valley fill contact. The transition zone from a zero free-air gravity correlation with bedrock-valley fill contacts to no coherent correlation occurs along a line that trends northerly from Mexico along longitude 110˚30' to 33˚ latitutde north (Sumner and others, 1976). The eastern boundary of the area of correlation is not known, but the Peloncillo Mountains do not correlate.

The detailed free-air gravity appears to infer a homogeneity and perhaps rigidity of the lithosphere for southeastern Arizona. The zero free-air contour that correlated with the bedrock-fill interface is probably in itself not significant; the correlation would have been less noticeable at any other value. The uniqueness of southeastern Arizona free-air gravity appears to fit the suggestions by other data that the area is a discrete lithospheric block within the Basin and Range province. It has been suggested that the free-air gravity infers that the area is in isostatic equilibrium (Sumner and others, 1976).

GRAVITY AND MAGNETIC COMPUTER MODELING

In order to compute the depth to bedrock across valleys on selected profiles, the regional gravity must be determined and an appropriate density contrast between basin-fill and bedrock chosen. Extensive measurements of thousands of samples for rock densities in southeastern Arizona are summarized by Aiken and Sumner (1974), and new work is reported by Bittson (1976) and Robinson (1975). Average Paleozoic and Mesozoic sedimentary and igneous rock densities of these measurements are 2.6-2.7 gm/cm^3. The Precambrian metamorphic and crystalline rocks have similar density values.

Eberly and Stanley (1978) compared seismic reflection profiles with surface and subsurface geology between Tucson and Yuma. The density and magnetic susceptibility of the pre-Basin and Range rocks (Eberly and Stanley's (1978) "Unit I" rocks) in grabens above crystalline basement could interfere in the interpretation of the gravity and magnetic anomalies of the valleys if depth to pre-Cenozoic bedrock is of interest. Should these older rocks be very thick and have high density or magnetic susceptibility values, they could give erroneously low values for pre-Cenozoic basement depths, although correct for Basin and Range structural relief.

Eberly and Stanley (1978) compared the results of a hole drilled to 3837 m depth in the Tucson basin with seismic reflection results. Their older Unit I rocks are 1400 m thick and consist of basaltic andesite tuff and conglomerate. Examination of the Compensated Neutron formation density log for the hole indicates densities of 2.6 gm/cm^3 for quartz monzonite (Tertiary-Cretaceous) at the bottom of the hole and in Unit I rocks. Unit II rocks above Unit I have densities which are distinctly lower, 2.5 gm/cm^3, decreasing up the hole to 2.3 gm/cm^3 at 1000 m depth. Although the logs have apparently not been calibrated, the relative variations of the densities in the hole indicate in this case it would be most difficult to identify the depth to the top of crystalline rocks with gravity data because of the small density contrast between Unit II rocks and the basement. The density contrast between Unit II and Unit I rocks averages —0.3 gm/cm^3.

Because of the very great depths and thicknesses of valley-fill, the density contrast between valley fill and basement used in computer modeling is —0.3 gm/cm^3. This is an average value that appears to best fit the density information and results of modeling in a variety of areas. Densities of shallow alluvium vary considerably and would affect the computed depth to the pediments by several hundred meters.

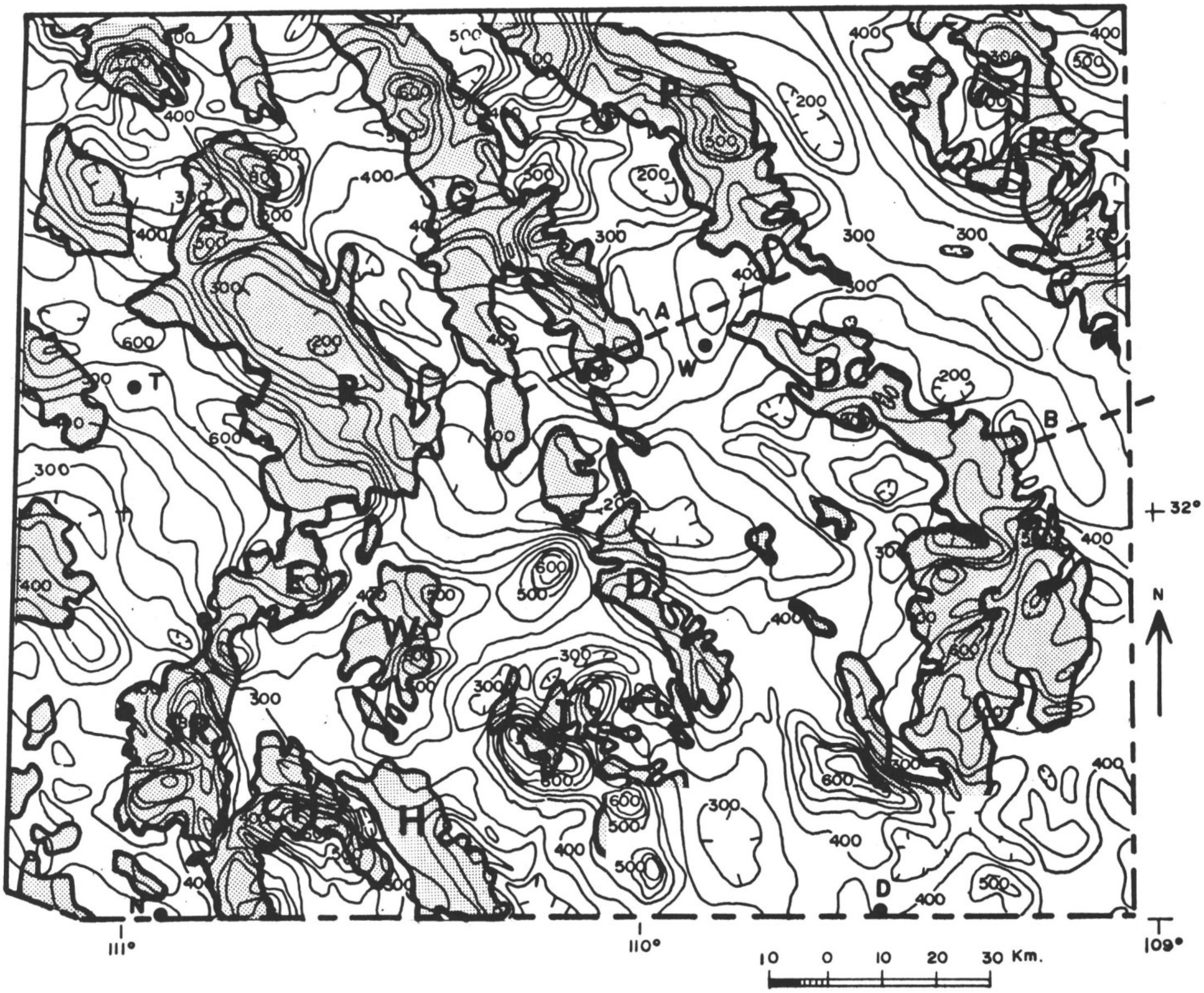


Figure 4. Residual aeromagnetic map. 50 gamma contour interval (Sauck, pers. commun.). Dashed lines A and B are magnetic model profiles. See Figure 2 for other explanations.

Of great importance is the determination of the regional gravity gradient, which is mainly due to regional density changes in basement rocks and deeper crust and mantle. For gravity models of basin-fill in the valleys, a linear gravity gradient has been used from one side of the valley to the other. It should be recognized that errors in the definition of the regional gravity could generate errors in depth to bedrock as large as those generated by errors in density contrast.

There are 8 profiles along which the gravity was interpreted by computer modeling. The position of each profile is shown on the gravity map (fig. 2). An iterative curve-fitting gravity modeling program for alluvium-filled basins is applied to these gravity profiles (West, 1972). The Bouguer gravity and the regional gravity values are plotted on the figures, the residual anomaly being the difference between them. The theoretical gravity effect of the fitted model is not shown because the difference between it and the calculated residual gravity was everywhere less than 0.3 milligals. The surface of topography, the top of the interpreted "bedrock" (bottom surface) and the known geology are also shown in profiles 1-8 and A, B. Drill holes located near the profiles are shown; the identification numbers of the drill holes and geological data are from Aiken and Sumner (1974).

In addition to the gravity profiles, two magnetic profiles (A and B) are modeled (fig. 4). The two-dimensional magnetic models were generated by successive trials with a Talwani-type polygonal-body modeling routine. Magnetic susceptibilities in the modeling have been chosen empirically by adjusting the computed anomaly amplitude to the observed within certain reasonable limits.

STRUCTURE OF VALLEYS IN SOUTHEASTERN ARIZONA

Among the valley systems in southeastern Arizona, the two easternmost valleys, the elongate Gila River-San Simon and Aravaipa-Sulphur Springs valley systems, have the largest am-

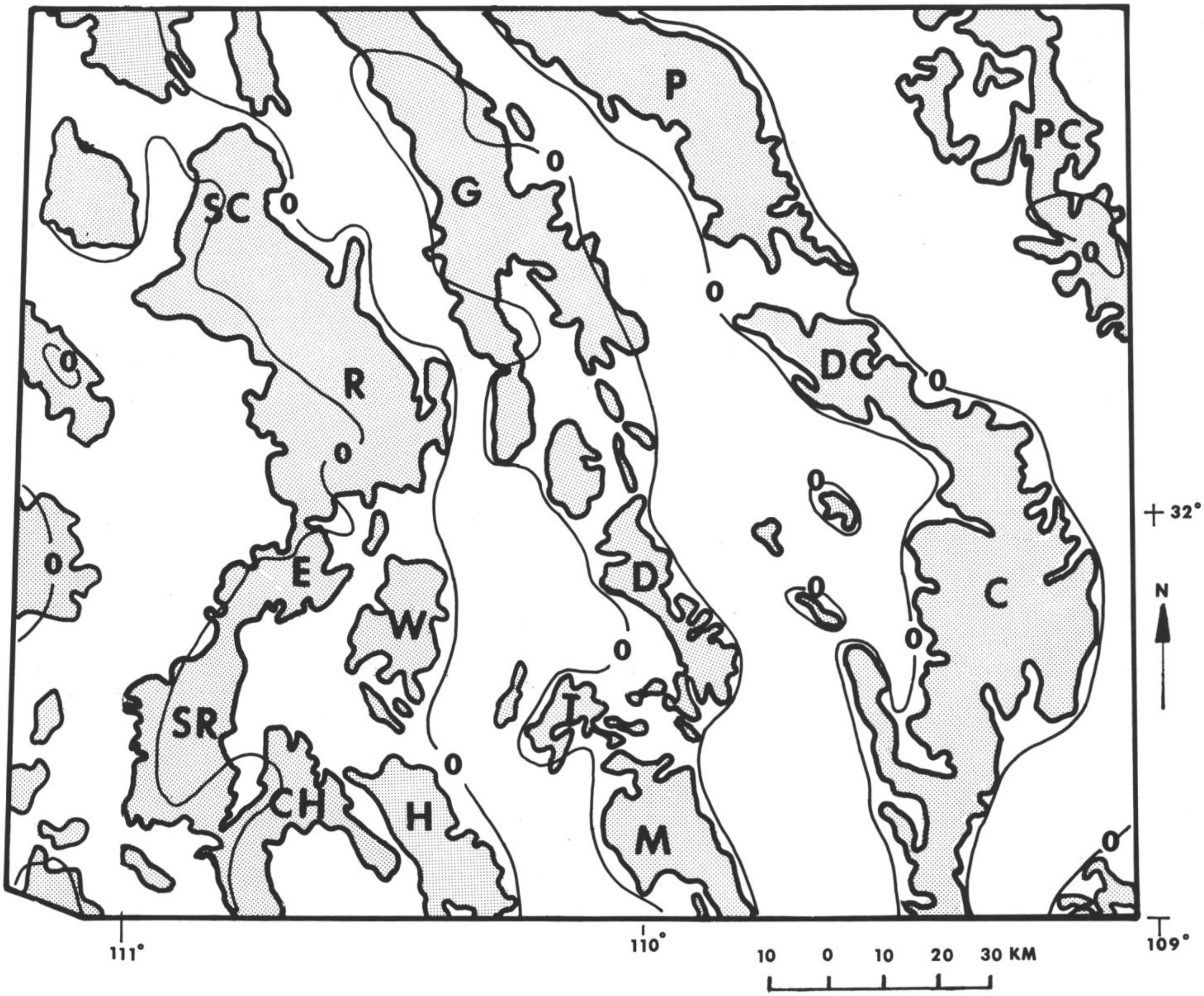


Figure 5. Map of free-air zero contour. See Figure 2 for further explanation.

plitude gravity and magnetic anomalies. Both gravity and magnetic anomalies are generally elongate parallel to the valleys.

Northeast of the Dos Cabezas Mountains the gravity and magnetic anomalies indicate that the subsurface basement is structurally complex and perhaps as shallow as 152 m (Eaton, 1972). One hole on a local gravity low penetrated 1253 m of Tertiary sediments and volcanic rocks and bottomed in sediments of questionable Cretaceous age. Another hole to the south into a gravity low was abandoned in Cretaceous rocks at a total depth of 2033 m.

Profile 6 (fig. 6) extends from the northern Chiricahua Mountains eastward to the Peloncillo Mountains. Pediments on both sides of the valley extend under the alluvium several kilometers before steep faults are encountered. A nearby magnetic profile, B (fig. 7), shows both the gravity and magnetic modeling results superimposed. There is an excellent correlation between the models of the structural low of the valley from the gravity and magnetic data, both indicating at least 3000 to 3500 m of valley-fill.

DH-21, close to Profile 6 (fig. 6) and the deepest drill hole in Arizona prior to 1969, encountered approximately 1524 m of Cenozoic tuff above the total depth of 2310 m. Other drill holes in this part of the valley also found thick sections of volcanic rocks. Because Precambrian granite is exposed in the Chiricahua Mountains, a vertical displacement of 4500 m may exist in this area.

In the southernmost part of San Simon Valley and the northernmost part of San Bernardino Valley southeast of the Chiricahua Mountains, the magnitude of the amplitude of the residual gravity anomaly is the same (25 milligals) as that in the deepest parts of the valleys to the north, indicating similar thicknesses of fill. A narrow magnetic high extends into and across the structural low indicated by the large negative gravity anomaly, but a parallel striking step in the gravity is also seen, indicating much more shallow basement in the southern San Bernardino Valley. The gravity high in this area trending across the valley seen in the state map of West and Sumner (1973) is an error in the data.

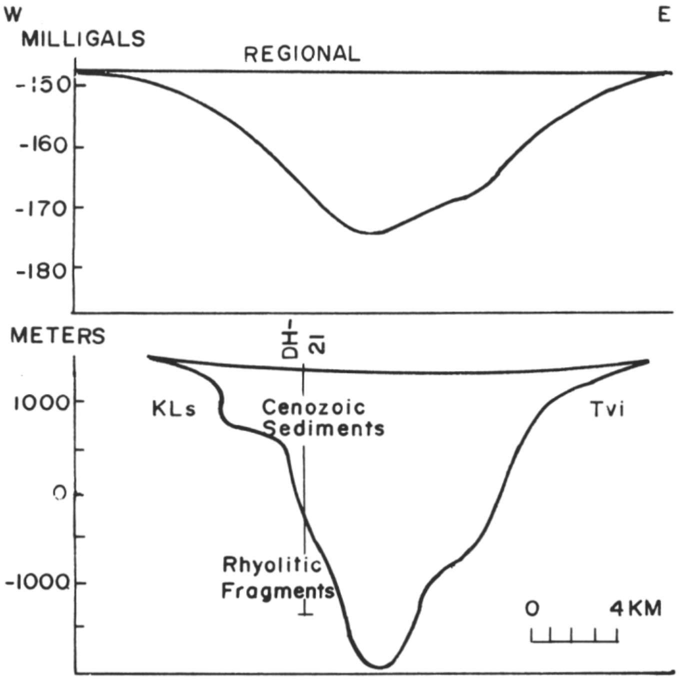
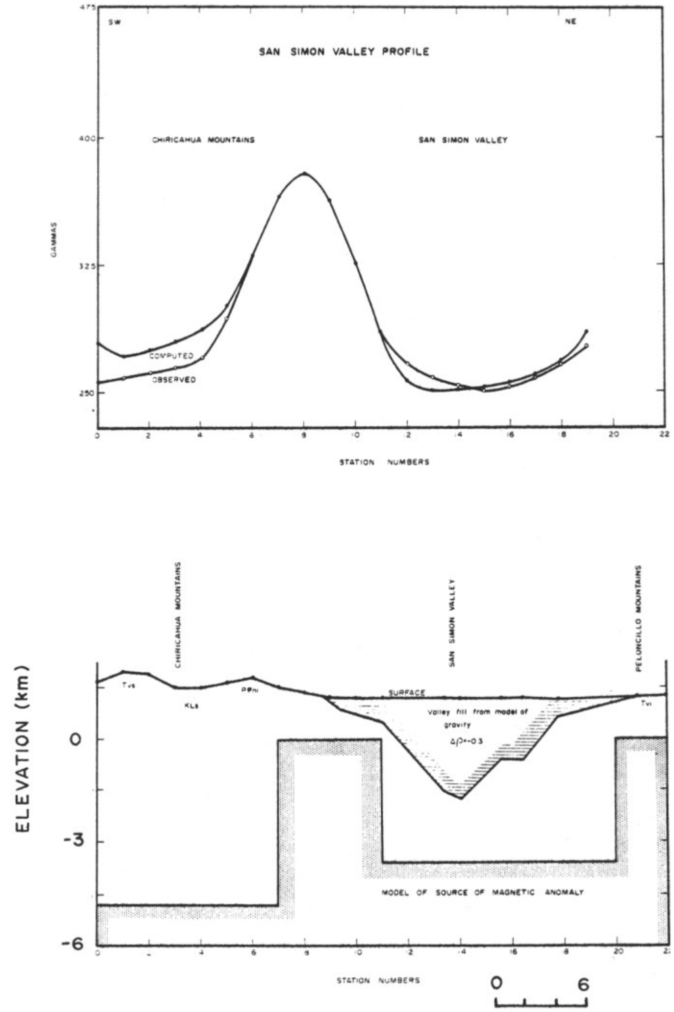


Figure 6. Gravity profile 6. Traverses San Simon Valley. Upper diagram is Bouguer gravity and regional anomaly. Lower is computed model. Drill holes are labeled "DH," and numbers are from Aiken and Sumner (1974). Geology along the hole is summarized. Exposed geology, KLs—Bisbee Gp, TVi—Tertiary intermediate volcanic rocks. Modified from Aiken and Sumner (1976).



Profile B

Figure 7. Magnetic profile B. Upper profile is observed and computed values of model of source of anomaly shown in lower diagram (stippled). A model of the valley-fill from gravity profile 6 is superimposed (horizontal lines). Geology is from Wilson and others (1969). Modified from Aiken and Sumner (1974).

The next valley to the west of the San Simon-San Bernardino Valley is Sulphur Springs Valley. Outcrops of basement rocks occur near the center of the valley in several areas, unlike the previous valleys, indicating a more complex structure.

As before, very good correlations appear between the models derived from gravity (Profile 1, figs. 2, 8) and magnetic (Profile A, fig. 9) anomalies in the northern valley near Willcox. Profile B corresponds to part of the geologic cross-section 8a-8b of Wilson (1962). The silicic volcanic rocks are 300 m thick on the west side of the valley assuming a density contrast similar to -0.3 gm/cm^3, making it difficult to separate the effects of silicic volcanics from those due to valley-fill. The interpreted basement over the easternmost part of Profile 1 is probably denser intermediate volcanic rocks inferred to lie directly upon Paleozoic rocks. On the east flank of the structural low indicated by gravity modeling, a drill hole penetrated Cretaceous rocks at 1768 m.

To the south, modeling along Profile 2 (fig. 10) indicated a complicated pattern of block faulting. A deep graben occurs along the southward extension of the graben modeled on Profile 1. The amplitude of the residual gravity is similar to that along Profile 1, with valley-fill thickness in the range of 3500 m.

The structure along Profile 3 (fig. 11) is complex like Profile 2, indicating the Pat Hills ridge and another ridge buried to the west. The gravity and magnetic anomalies show the presence of a subsurface ridge extending northward from Pat Hills. As can be seen on the western part of Profile 3 (fig. 11), the depth to basement along the profile is much less than the depths to basement indicated to the north. A drill hole bottomed at 1005 m in unconsolidated Cenozoic material to the north of the line in the gravity low west of Pat Hills.

The basement high west of Pat Hills appears to extend southeasterly to the Chiricahua Mountains. To the east of Pat Hills the coincidence of a gravity and a magnetic anomaly is caused by structural relief and not a lateral magnetic susceptibility change.

The north-south trend of the maximum structural low in Sulphur Springs Valley indicated by gravity data changes direction between Profiles 4 (fig. 12) and 5 (fig. 13). A graben with narrow pediments and a maximum thickness of fill of 2000 m is seen along Profile 4 (fig. 12). A drill hole at the east end of the line penetrated 210 m of alluvium, 300 m of porphyry(?), mudstone and conglomerate and then andesite. The andesite has a magnetic susceptibility of 4500 x 10^{-6} cgs units and a density of 2.6 gm/cm^3. The alluvium and sequence of por-

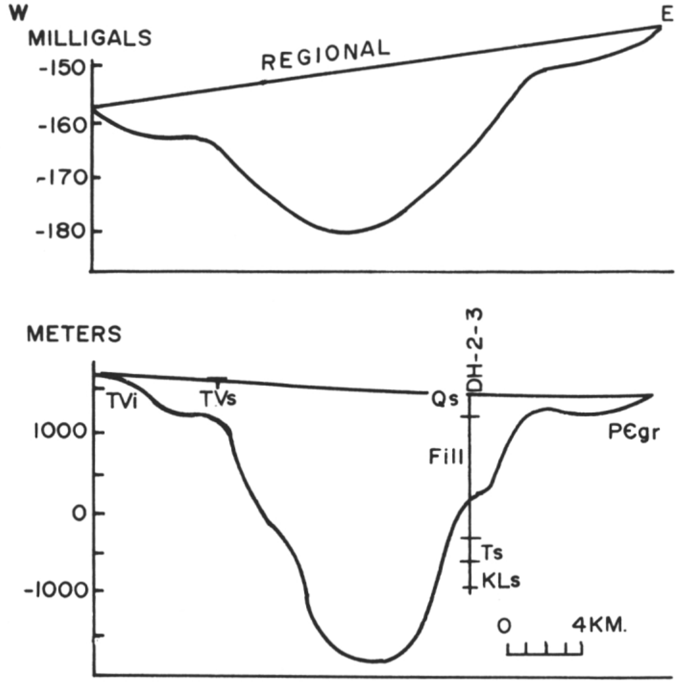


Figure 8. Gravity profile 1. Traverses Sulphur Springs Valley. See Figure 6 for explanation. TVs—Tertiary silicic volcanic rocks, Qs and Ts—Quaternary and Tertiary sediments, pЄgr—Precambrian granite. Modified from Aiken and Sumner (1974).

phyry, mudstone and conglomerate have densities of 2.0 and 2.4 gm/cm^3, respectively, and negligible magnetic susceptibility even for the volcanics. A large magnetic high in the area south and southeast of Elfrida is Sauck's (1972) Anomaly 54, which he describes as one of the few positive magnetic anomalies occurring in the valleys but which is actually on the pediment.

There are several drill holes close to Profile 5 (fig. 13). Andesite at the bottom of DH-12 (1333 m) could be of Cretaceous age similar to the andesitic flows found in the mountains to the east. Considering the salinity of the sediments, the density contrast may be greater than —0.3 gm/cm^3, and the interpreted bedrock depth would equal the depth to the andesite. However, a structural relief of only 510 m is required to fit the three elevations for the known or predicted levels of Precambrian rocks at DH-12, DH-34 and DH-24 if the andesite in DH-12 is basement. This is in comparison to the apparent minimum of 2000 to 3000 m of relief known or indicated elsewhere. It would appear likely that the andesite at DH-12 is still part of the basin-fill rather than basement.

As the International border is approached the amplitude of the residual gravity values remains constant, indicating that the basin structure is as deep in the south as it is in the north.

Bedrock outcrops are seen between the Santa Catalina and Galiuro mountains and between the Whetstone and the Dragoon mountains, along the San Pedro River. Several magnetic anomalies trend across San Pedro Valley east of the Whetstone and Rincon mountains and gravity lows in these areas of the valley are not prominent. East of the Santa Catalina Mountains the valley graben is east of San Pedro River.

There is no prominent relationship between outcrop geology and gravity and magnetic anomalies in San Pedro Valley, as observed in the valley systems to the east. This may be due either to very dense Quaternary-Tertiary sediments and volcanic flows in valley fill, or to a structural low shallower than those in the eastern valleys. A drill hole between the Rincon and Galiuro mountains was still in Cenozoic rocks at the total depth of 330 m.

The general area northwest of the Tombstone Hills is a structural high. A local basement low is interpreted by Spangler (1969) east of this high near the west flank of the Dragoon Mountains. The narrow gravity low shown on Profile 7 (fig. 14) appears to terminate abruptly to the south. A magnetic low in the same general area also terminates to the south.

Southwest of the Tombstone Hills gravity and magnetic data define a structural low extending southeastward into Mexico. When the gravity and magnetic anomalies are used to define the structural trend of the San Pedro, Sulphur Springs and Gila River-San Simon-San Bernardino valley systems, the structure of the last two systems is generally consistent with their respective physiographic locations. Magnetic anomalies suggest that the San Pedro Valley graben is narrow and trends southward along the east flank of the Whetstone Mountains to about the north end of the Huachuca Mountains, thence southeasterly to the border with Mexico. The area between the Whetstone, Dragoon and Tombstone Hills appears to be an anomalously strong core around which much of the large-magnitude Basin and Range block-faulting occurred.

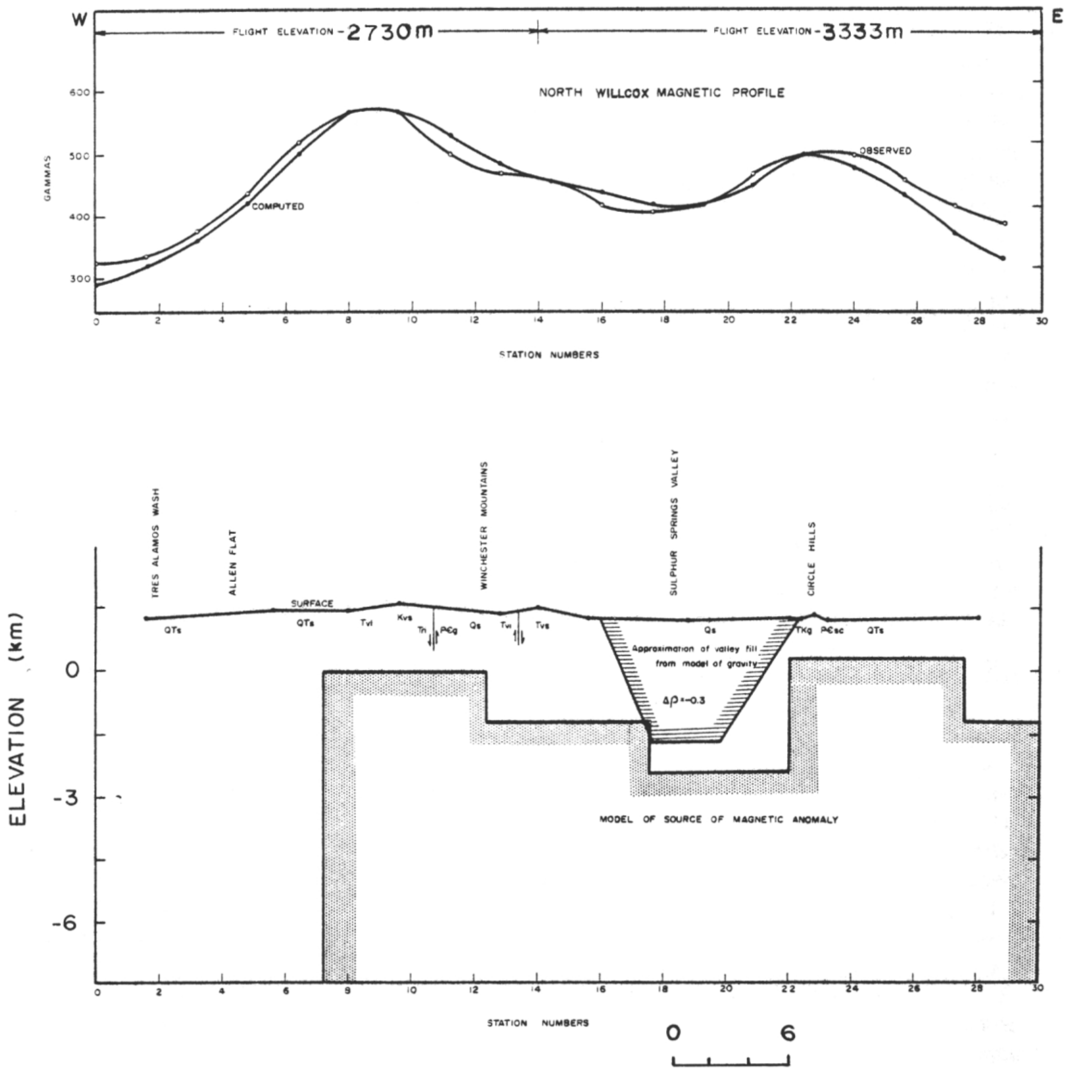
A well-defined gravity anomaly and a partially coincident magnetic anomaly occurs in the Sonoita basin (Profile 8, fig. 15) (Bittson, 1976). Very strong magnetic anomalies are associated with these mountains (Whetstone, Santa Rita, Patagonia and Huachuca). With one exception, all of the drill holes drilled within or close to the deep part of the Sonoita basin, as indicated by the gravity anomaly, bottomed at depths ranging from 230 to 1034 m. At least three of these holes penetrated Cretaceous strata beneath the Quaternary-Tertiary sedimentary deposits at depths ranging from 161 to 213 m.

From modeling and gravity and magnetic anomaly patterns a generalized map of major basin structures is shown in Figure 16.

RESIDUAL BOUGU ER GRAVITY ANOMALY ANALYSIS

In Arizona a long-wavelength Bouguer gravity anomaly gradient dominates the Bouguer gravity anomaly map, obscuring shorter wavelength anomalies (West, 1972). High-amplitude residual Bouguer gravity anomalies reflecting thick, low-density basin-fill in the Basin and Range province are distorted by a regional gradient but are not completely obscured (Aiken and Sumner, 1974). Basin-related anomalies are easier to interpret because many parameters of the anomalies and their possible causes are known. Therefore, a separation between regional and residual gravity anomalies can be easily carried out for a particular basin as discussed earlier. However, relating the configuration of one basin to another over a large area is a more complex problem.

Magnetic anomaly trends (fig. 3) traverse the state from the Basin and Range province to the Colorado Plateau province, often cutting across the surface structural grain (Aiken, 1976). Gravity anomalies coincident with magnetic anomalies, if they



Profile A

Figure 9. Magnetic profile A. See Figure 7 for explanation. Modified from Aiken and Sumner (1974).

exist, may be overshadowed not only by the long-wavelength regional anomaly discussed above but also by high-amplitude, short-wavelength anomalies reflecting shallow sources, such as Tertiary basins. These short and long-wavelength gravity anomalies can together obscure other anomalies of interest. A solution may be one of passing the data through a band-pass filter to remove the long and short wavelength anomalies.

A residual Bouguer gravity anomaly map of Arizona (Aiken, 1975) has been produced in which at least the long-wavelength Bouguer gravity anomaly described above is removed (Aiken, 1976, 1978). A brief description of the construction of the residual anomaly map is discussed here, the details having been given in Aiken (1976, 1978).

There is an almost exact correlation between the long-wavelength (800 km) Bouguer gravity anomaly (fig. 17a) in Arizona and the elevations of gravity stations (fig. 17b) in the area of interest and throughout Arizona. The positive correlation between the regional gravity anomaly and the station elevation trend is a direct consequence of the removal of the gravitational effect of the mass of isostatically compensated terrain. If the terrain is completely compensated, the average free-air gravity anomaly value will not vary. If the Bouguer correction has a sea-level reduction datum, the gravitational effect of all the mass between the level of the station and the sea-level datum is removed. Such a correction will result in a Bouguer anomaly which correlates with elevation, by 11 milligals per 100 m, the magnitude of the Bouguer correction.

Because a coincidence exists between a long-wavelength regional Bouguer gravity anomaly and elevation, a separation between a residual and a regional anomaly can be made by utilizing elevations. The magnitude of the Bouguer correction depends on the difference between the elevation of the station and the elevation of the reduction datum. A regional elevation datum based on topographic elevations in the Bouguer correction can produce results similar to the application of a high-pass filter on the Bouguer gravity anomaly values if a trend surface of the elevations of topography outlines components of isostatically compensated terrain. The gravitational effect of the mass between the station elevation and the regional elevation datum will be removed. The regional Bouguer gravity

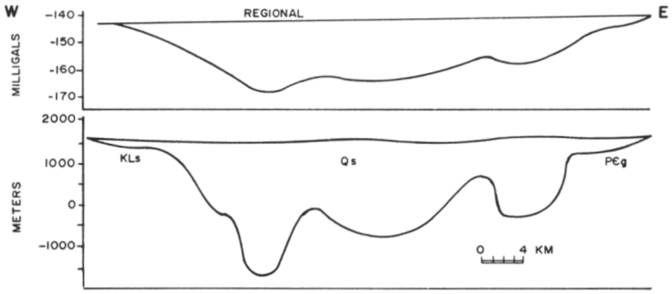


Figure 10. Gravity profile 2. Traverses Sulphur Springs Valley through Willcox. See Figures 6 and 8 for explanation. Modified from Aiken and Sumner (1974).

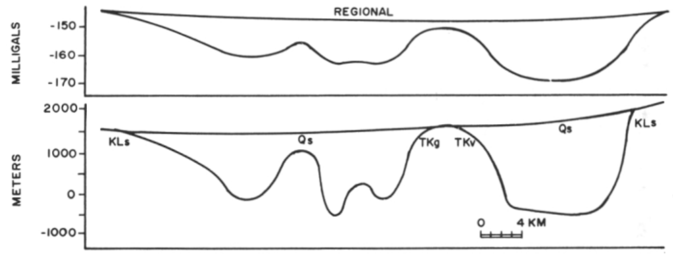


Figure 11. Gravity profile 3. Traverses Sulphur Springs Valley-Pat Hills. See Figures 6 and 8 for explanation. TKg—Laramide granites, TKv—Laramide volcanics. Modified from Aiken and Sumner (1974).

anomalies correlating with elevations should be eliminated or more accurately, subdued.

The locations of the gravity stations are not usually ideally spaced or located for accurate sampling of the topography and geology, and this is particularly true of Arizona. Many more stations are located on low density valley-fill at lower elevations. The average Bouguer gravity anomaly and elevation may have bias. Therefore, if topography can be used to predict the regional Bouguer gravity then topographic maps should be digitized to accurately sample the area and define the regional anomaly (compare fig. 18a with fig. 17b). Equation used to compute residual values is:

$$g_{RB}\ g_o\ g_T\ g_F\ [27rGp(E_s—E_R)1, \text{ where} \qquad (1)$$

g_o = observed, g_T = theoretical, g_F = free-air correction, G = universal gravitational constant, p = density, E_s = station elevation and E_R = regional topographic datum.

A regional topographic surface (E_R) derived for the entire state is used to compute g_{RB} for the residual gravity map in Figure 19.

SUMMARY AND DISCUSSION

In southeastern Arizona there is a correlation between gravity and magnetic anomalies from shallow sources. Gravity and magnetic anomalies are strongly related to the distribution of the basins; the lateral changes in density of the consolidated bedrock or deeper crustal lithologies are obscured. Aeromagnetic anomalies over the valley can be shown to be related to structural lows also. Cross-cutting magnetic highs are never found on the state aeromagnetic map. The local magnetic high in a valley can be related to accompanying gravity anomaly highs which are related to subsurface structures and indicate structural highs.

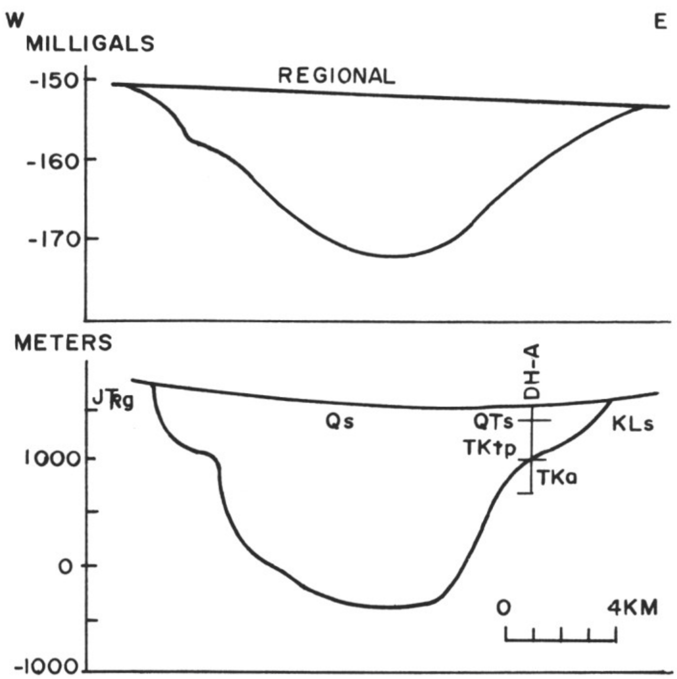


Figure 12. Gravity profile 4. Traverses Sulphur Springs Valley through Elfrida. Explanation as above. JTRg—Jurassic-Triassic granite. Modified from Aiken and Sumner (1974).

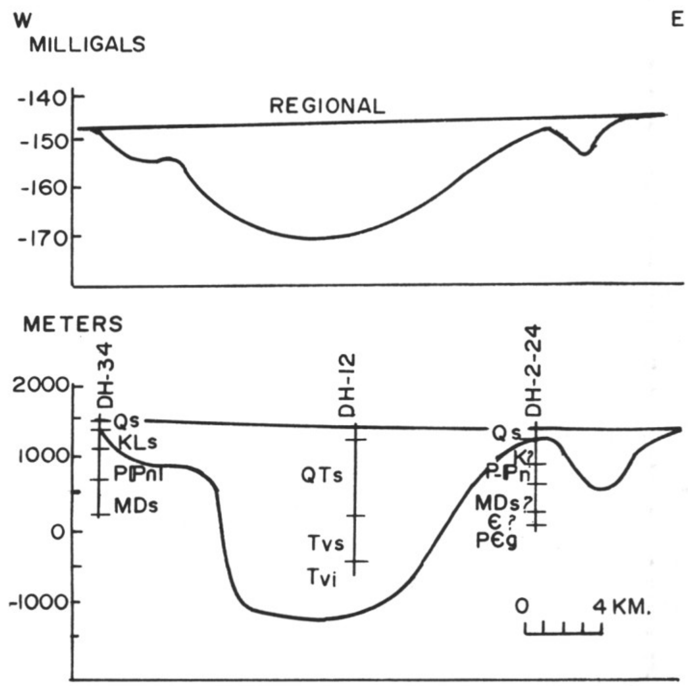


Figure 13. Gravity profile 5. Traverses Sulphur Springs Valley through McNeal. Explanation as above. See Moore and others (1969) for symbols. Modified from Aiken and Sumner (1974).

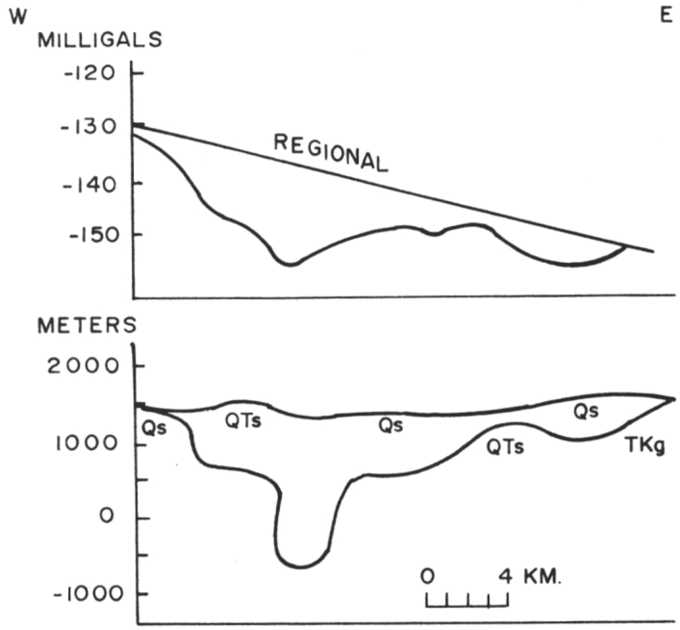


Figure 14. Gravity profile 7. Traverses San Pedro Valley through Benson. Explanation as above. Modified from Aiken and Sumner (1974).

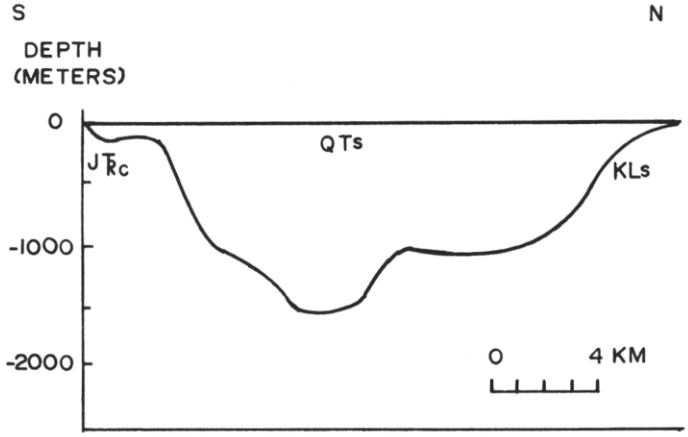


Figure 15. Gravity profile 8. Traverses Sonoita basin. Only results of gravity model are shown relative to horizontal datum. Explanation as above. Modified from Bittson (1976).

Significant magnetic anomalies are produced where the magnitude of the structural relief due to block faulting is on the order of 1000 m and there are exposures of granitic intrusive rocks, especially Precambrian (Sauck, 1972) in the mountains. Less magnetic schists, sedimentary rocks and alluvium overlying these crystalline rocks do not have a discernible effect on the magnetic anomalies, nor do most of the considerable volcanic flows and tuffs found in the basins.

The shorter wavelength magnetic anomalies in southeastern Arizona reflect Basin and Range structure just as do the gravity anomalies. Gravity lows and magnetic highs do not coincide since each reflects opposite effects, negative and positive structures respectively. Steep gradients along the boundaries of both prominent magnetic and gravity anomalies in the valleys can be related to basin faults. Magnetic highs in the valleys reflect structural highs and therefore an absence of large relief resulting from Basin and Range faulting. This analysis takes into account steeper, shorter wavelength (and therefore shallower) anomalies and not the regional-scale anomalies which are caused by sources much deeper in the crust.

A gravity gradient in the residual Bouguer gravity anomalies trending northwesterly has a 20-mgal change across a 50 km-wide zone (fig. 18b) and traverses the entire state. To the north of this zone the dominant trend in the magnetic and residual Bouguer gravity anomalies is to the northeast; to the south the dominant trend in the anomalies is to the northwest.

Magnetic trends on the aeromagnetic map of Arizona parallel major long-wavelength residual Bouguer gravity anomalies. A regional magnetic high in southern Arizona trends west-northwest through Tucson coinciding with the northwest-trending gradient on the residual Bouguer gravity. This gradient in the gravity and coincident magnetic anomalies will be called the Tucson trend.

Warren (1969) interpreted from seismic refraction an upper mantle under the Colorado Plateau that is denser than that under the Basin and Range province of Arizona. The transition begins in the Basin and Range south of Phoenix. There is no support for his specific model of the cause, a high density upwelling in the mantle, by other geophysical studies in the area. Johnson (1967) analyzed different seismic and gravity data over the same profile that Warren (1969) used but interpreted the gravity anomalies as related to lateral changes in the density of the lower crust. The gravity anomaly defined by Johnson (1967) and Warren (1969) is the northern extension of the Tucson trend. The northeasterly long-wavelength residual gravity increase across southeastern Arizona indicates the same increase in density.

The compensation of the mass of the terrain can be accomplished by increasing the thickness of the crust as the elevation increases. The application of the regional elevation datum, however, attempts to use the coincidence between terrain variation, Bouguer gravity anomalies and isostatic compensation. If variation in the thickness or density of the crust occurs rapidly in relation to the wavelength of the regional elevation datum, the residual Bouguer gravity anomalies may reflect variations of crustal thickness or density.

All the geophysical parameters infer a fundamental boundary in the crust or upper mantle in southeastern Arizona, and imply that it has a northwesterly trend. Drewes (1978) suggested that pre-Cordilleran structural features provided constraints to later events. Segments of faults reactivated repeatedly with diverse directions of movement. Major Precambrian northwesterly trends have produced structural anisotropy that guided responses to later stresses and channeled movement of magmas in Triassic to Mid-Cretaceous time. Granitic stocks were emplaced and major blocks uplifted along complex faults such as the Sawmill Canyon complex fault along the northern flank of the Canelo Hills.

Recurrent igneous and structural activity as seen by Drewes (1978) should be reflected in the basement and deeper crustal lithologies and therefore in aeromagnetic and gravity anomalies. The apparent discontinuous nature of the Tucson anomaly trend southeast of Tucson is due to the closer line spacing (1.6 km vs. 5 km) where short wavelength anomalies caused by deep basins obscure the general trend of an anomaly with a deeper source. The Tucson trend coincides with Drewes'

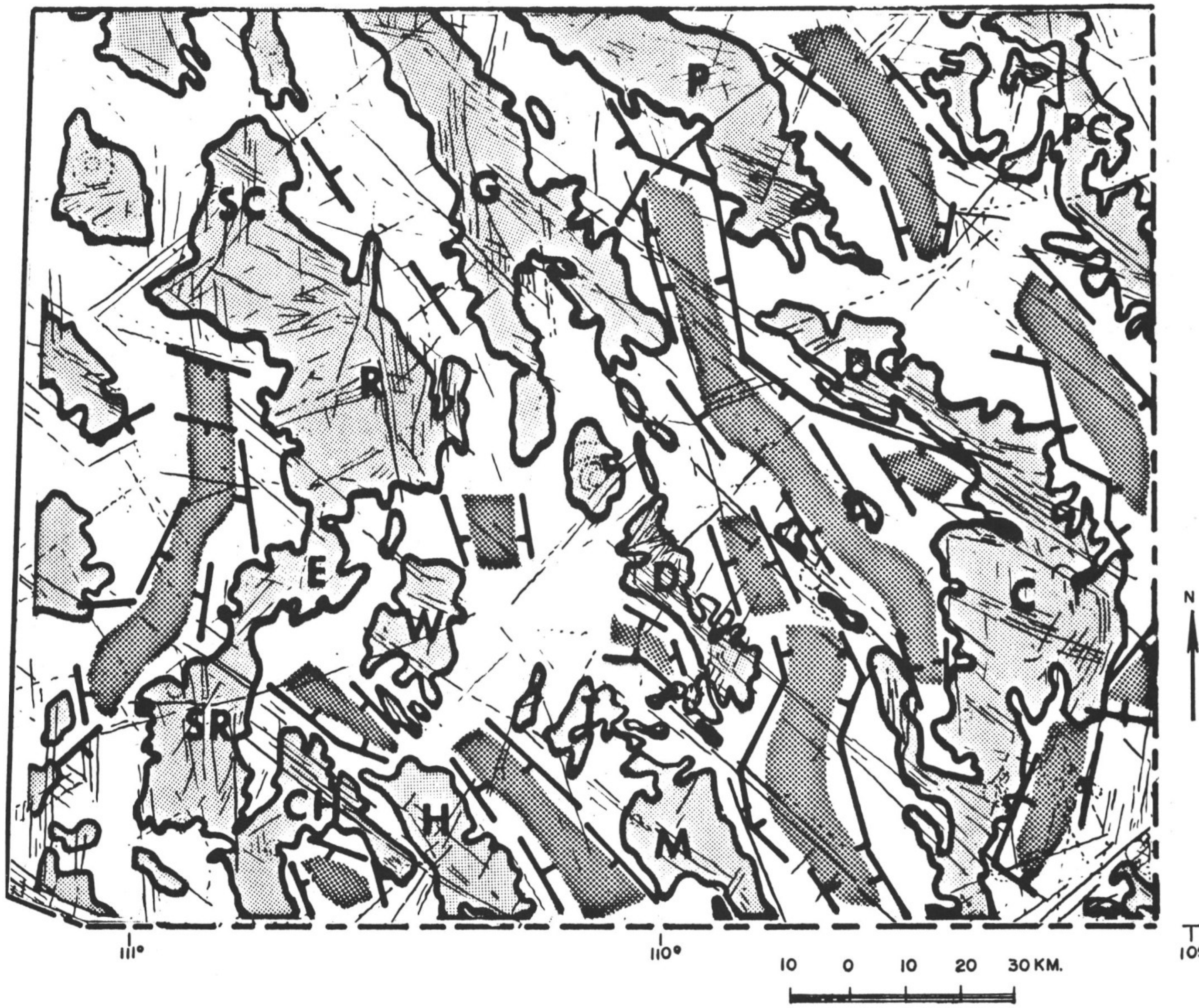


Figure 16. Structure map. The heavy lines are the interpreted major basin grabens with the crossbar on the downthrown side. The stippled areas are the deepest parts of the basins. The finer lines are lineaments, interpreted from Landsat imagery by Lepley (1977). See Figure 2 for further explanation.

(1978) northwest trend of 75 m.y.-old andesite to dacitic igneous rocks.

The pre-Basin and Range structural trends are northwesterly and appear to be as old as Precambrian. The Sawmill fault trend is an example of an older structure controlling the younger basin faults (Sonoita basin). Numerous other examples of correlations can be seen on Figure 16 when Landsat lineations (Lepley, 1977) are superimposed on the basin faults. The regional trends in Landsat lineations are also strongly northwesterly, indicating that the Precambrian structural fabric may be affecting more recent structure. Regional aeromagnetic and residual Bouguer gravity anomaly trends are also strongly lineated to the northwest (figs. 4, 19). The lithologic variations in the lithosphere reflect all the effects of past tectonic history and are reflected as magnetic and gravity anomalies. Basin and Range structure correlates with Landsat lineations and with the older northwest trend in many areas. The relationship appears to be similar to that described in New Mexico, where surficially the general structure is related to extensional stresses of Basin and Range tectonism but in detail is controlled by older structures (Ramberg and Smithson, 1975).

A northwest trend in all the data is evident, but it may not necessarily be the Texas lineament as classically defined (Drewes, 1978) if the trend is followed into adjacent New Mexico and Mexico. Several trend directions are evident which have been correlated with several structural elements of various ages (Drewes, 1978; Aiken, 1977).

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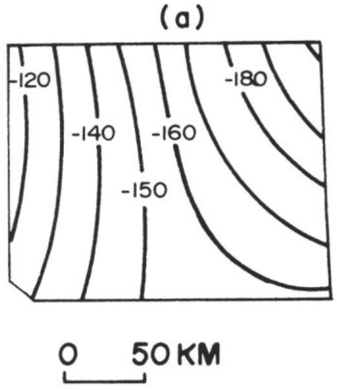

Figure 17. Trend surfaces of (a) Bouguer gravity and (b) elevations of gravity stations of southeastern Arizona. Wavelengths are 800 km. Contour intervals are 10 milligals and 150 m respectively. Area covered is the same as Figures 2, 4 and 19. Modified from Aiken (1976).

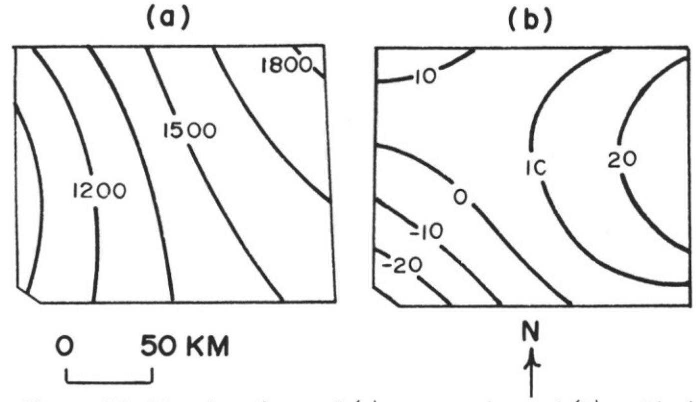

Figure 18. Trend surfaces of (a) topography and (b) residual Bouguer gravity anomalies of southeastern Arizona. Wavelengths are 800 and 400 km and contour intervals are 150 m and 10 milligals respectively. Area covered is same as Figures 2, 4 and 19. Modified from Aiken (1976).

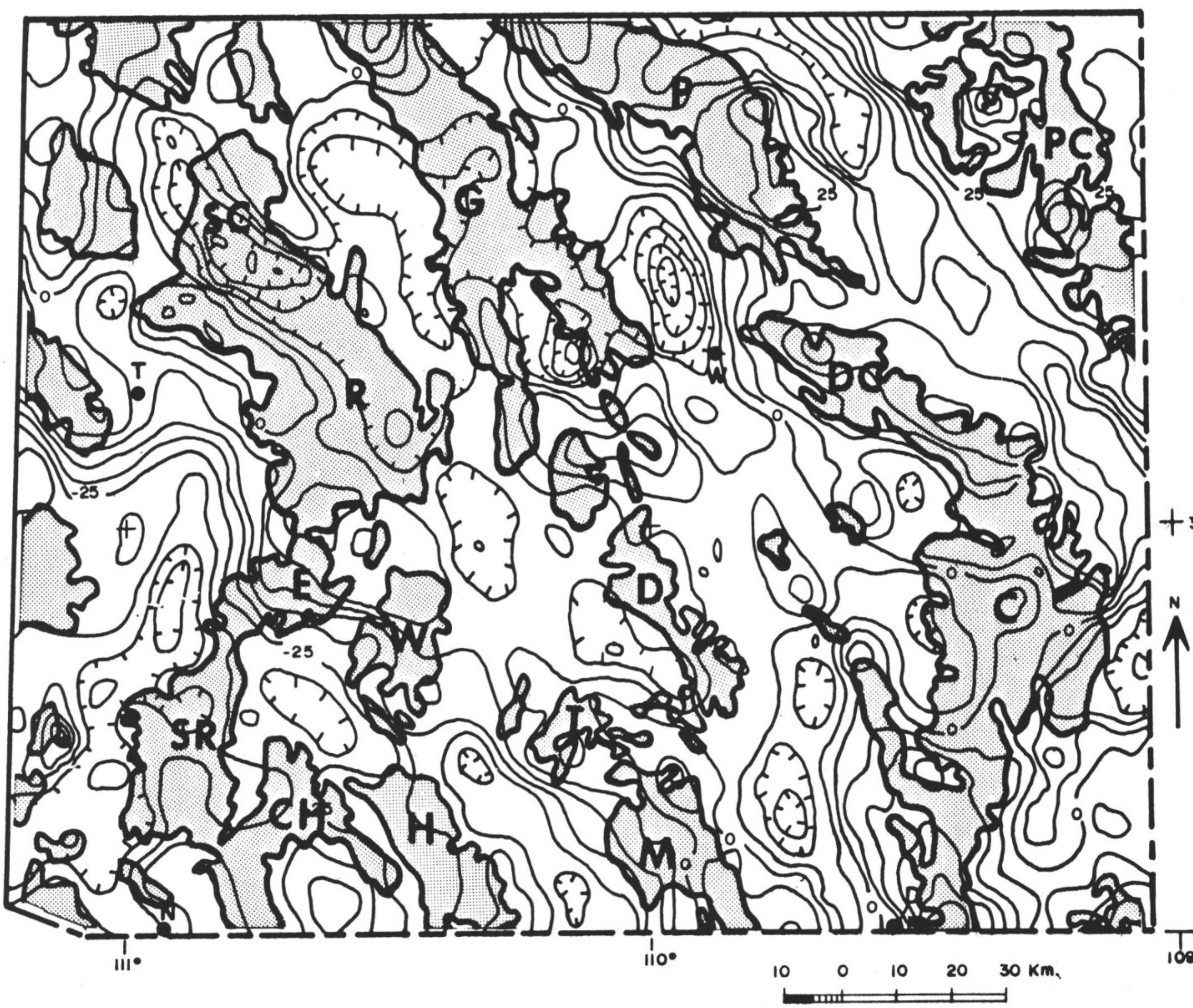

Figure 19. Residual Bouguer gravity anomaly map. Contour interval 5 milligals. See Figure 2 for explanation. Modified from Aiken (1976, 1978). Derived by using equation (1), with a regional topographic datum (Fig. 18a) defining E_R.

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