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Preliminary results of modeling the gravity anomaly field in the upper San Pedro basin, southeastern Arizona

by

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ABSTRACT

A preliminary analysis is presented of the complete (terrain corrected) Bouguer gravity anomaly field in the area of the upper San Pedro Valley from near Fairbank, Arizona southward to the border with Mexico. Fifty-four new gravity stations were acquired in the area to supplement existing coverage. Preliminary models of the gravity anomaly suggest the presence of two north- to north-northwest-trending structural subbasins beneath the upper San Pedro Valley. The northern subbasin, named the Huachuca City structural subbasin, contains about 1,100 m of basin-fill sediments, and the southern subbasin, named the Palominas subbasin, contains about 2,300 m of basin-fill sediments. The Palominas subbasin is probably a half graben, deepest on the western side adjacent to the Huachuca Mountains. A north-northwest-trending zone of Pleistocene fault scarps between the San Pedro River and the Huachuca Mountains may mark the location of part of the bounding fault zone. The gravity anomaly map suggests that the Huachuca City structural subbasin is separated and offset westward from the Palominas structural subbasin by a complex northeaseast-trending zone of relatively high bedrock beneath Fort Huachuca and Sierra Vista that contains several local bedrock highs and lows.

No evidence was found to support the presence of a proposed buried bedrock high on the west side of the Palominas structural subbasin near Nicksville. Evaluation of well data indicates the bedrock high is an artifact of several mislocated wells on the draft structure contour map prepared by the Arizona Department of Water Resources.

INTRODUCTION

The San Pedro River flows northward through about 200 km of the southern Basin and Range province from Cananea, Sonora to the Gila River at Winkleman, Arizona (fig. 1). Although the San Pedro River Valley (and the structural basin it occupies) trends north-northwest overall, it is underlain by least five irregularly-shaped buried subbasins separated from each other by chiefly northeast-trending structures. The gravity and well data reported here are part of a multidisciplinary program to delineate the subsurface shape and extent of the structural subbasins that comprise the San Pedro basin, and to estimate the character and distribution of the basin-fill sediments. This information will provide the basis for ground-water models and is a necessary first step for other geologic and hydrologic studies of the San Pedro basin. Initial work is focused on the upper San Pedro Valley, from the international border to the vicinity of Fort Huachuca and Sierra Vista, because of the immediate need for data for ground-water modeling in this area.

Statement of the Problem A structure contour map of the buried bedrock surface beneath the upper San Pedro Valley was prepared by the Arizona Department of Water Resources (ADWR) based on study of drillers' logs of water wells. The structure contour map suggested that a shallow bedrock high extended eastward from the Huachuca Mountains in the vicinity of the community of Nicksville (fig. 1). Because of the uncertainties inherent in the interpretation and location of drillers' logs and because the geometry of the bedrock high did not correspond to the basin geometry determined geophysically by Oppenheimer and Sumner (1981), the ADWR requested that the U.S. Geological Survey conduct a detailed gravity survey to define the geometry of the bedrock surface near Nicksville.

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GRAVITY ANOMALY DATA

Gravity data were compiled for the upper San Pedro Valley and adjacent ranges. Existing data were retrieved from the Defense Mapping Agency's gravity data library and from data reported by Halvorson (1984). These data were checked for reasonable values, adjusted to the International Gravity Standardization Network datum of 1967, and used to compute complete (terrain corrected) Bouguer gravity anomaly values. The initial map contained several obviously erroneous data points. These were corrected if it was determined that the gravity station was either mislocated or had an incorrect altitude, or deleted if the observed gravity value itself appeared incorrect. Several stations were reoccupied to check their validity and insure that the data from the several surveys were on the same datum.

In the Nicksville area, there were insufficient gravity stations over the northeast part of the proposed bedrock high to delineate a gravity anomaly that might result from such a bedrock high. Accordingly, new stations were established in this area. New stations were also established on the eastern side of the basin in the Hereford area and into the foothills of the Mule Mountains where no data were available, as well as around the southern end of the Huachuca Mountains. In all, 54 new stations were established in October, 1994 by M.E. Gettings. These data were reduced and added to the existing data set to produce the complete Bouguer gravity anomaly map of figure 2.

BOUGUER GRAVITY ANOMALY MAP

Structural Subbasins of the Upper San Pedro Valley Preliminary interpretation of the Bouguer gravity anomaly map of the upper San Pedro Valley (fig. 2) suggests that this part of the valley is underlain by two north- to north-northwest-trending structural subbasins corresponding to gravity minima. The northern subbasin is herein called the Huachuca City structural subbasin and the southern one is called the Palominas structural subbasin. The subbasins are separated by a complex northeast-trending zone of relatively higher gravity that extends from south of Huachuca City on the north to opposite the mouth of Carr Canyon on the south. Assuming the -152 mgal contour corresponds approximately to the outer boundary of the structural subbasins, the magnitude of the southern gravity anomaly minimum shown on figure 2 is about 26 mgal and magnitude of the northern gravity anomaly minimum is about 15 mgal. The greater magnitude of the gravity anomaly minimum of the Palominas structural subbasin indicates that it is considerably deeper than the Huachuca City subbasin.

Comparison of this map with previously published maps (for example Halvorson, 1984) shows that the new gravity stations have defined the Palominas anomaly to be considerably more restricted in areal extent, with the minimum of the anomaly being about 4 km west of the San Pedro River (fig 1). The steep gravity gradient on the western side of the Palominas structural subbasin shown in figure 2 indicates that this subbasin is probably a half graben, with one or more bounding faults on its western side. The north-northwest-trending Pleistocene fault scarps mapped by Demsey and Pearthree (1994) east of the Huachuca Mountains (fig.1) probably record young movement along this system of bounding faults. There is a suggestion shown on figure 2 that the Palominas subbasin becomes shallower toward the border with Mexico, but more gravity stations are needed in the border area to delineate the anomaly shape.

The basin configuration beneath the Sierra Vista area is apparently complex and includes at least one local buried bedrock high adjacent to a shallow swale on the bedrock surface.

Thickness of Basin Fill Calculated from Gravity-Anomaly Data A preliminary inversion of the gravity anomaly map for thickness of basin fill is shown in figure 3. Normally, inversion of a gravity anomaly map for basin-fill thickness requires a residual anomaly that isolates the anomaly due to the lower density of basin fill from those due to other sources. In general, the most satisfactory way to do this is to model all the major anomalies in a combined model. At this time, however, there are insufficient data available to define the gravity anomalies associated with the Mule and Huachuca Mountains, and the simplified procedure described below was used to obtain a preliminary estimate of the magnitude of these anomalies.

Comparison of the gravity anomaly map (fig. 2) with the contact between bedrock and basin fill (fig. 1) shows that, to a first approximation, the gravity anomaly due to the Palominas structural subbasin is contained mostly within anomaly values less than the -152 mgal contour. Thus, 152 mgal was subtracted from the gravity anomaly grid and negative values (corresponding to areas over exposed bedrock) were set to zero. Also, areas of nonzero anomaly outside the basin were set to zero. This residual gravity anomaly was then inverted for basin-fill thickness using the forward modeling option of a gravity anomaly modeling program using parallelepipeds (Cordell and Henderson, 1968; Phillips and others, 1993), and a uniform density contrast of -0.4 g/cc. This value is in agreement with that used by other investigators in the Basin and Range province, but will be revised when the results of digitizing available density logs from boreholes in the San Pedro basin and density measurements of bedrock samples are completed. Although the absolute values of depth-of-fill estimates will change with changing density contrast, the relative shapes and depths of the subbasins will not.

Comparison of figure 3 with the actual bedrock-basin contact on figure 1 shows that the predicted edge of the basin agrees well with the observed edge over the Palominas structural subbasin but extends well into bedrock around the Huachuca City structural subbasin. Inspection of the gravity anomaly map (fig. 2) shows that there is a northward-increasing gradient of the gravity anomaly so that the subtaction of 152 mgal north of about latitude 31°31' gives too large a residual anomaly. Thus, basin-fill thickness estimates shown on figure 3 north of this latitude are probably about 300 m too large, especially on the west side of the basin. Maximum basin-fill thickness (depth of the subbasin) estimated by this model is about 2,300 m in the Palominas structural subbasin and probably about 1,100 m in the Huchuca City structural subbasin, taking into account uncertainties introduced by the northward increasing gravity gradient.

PROPOSED BEDROCK HIGH NEAR NICKSVILLE

Gravity Analysis The Bouguer gravity anomaly map (fig. 2) gives no indication of the presence of the shallowly buried bedrock high near Nicksville predicted by the ADWR structure contour map. The possibility that the high could be present but not show up on the gravity anomaly map was tested by computing the gravity anomaly that would result from this bedrock configuration, assuming standard density contrasts. A digital model of the basin-fill thickness was derived from the ADWR structure contour map. This was done by digitizing the contours of bedrock elevation at approximately 1.6 km intervals and using these values to compute a 1-km-interval square grid covering the map area. Digital topography values at a 1-minute interval of latitude and longitude were used to compute a 1 km interval grid of the surface elevation. Finally, the bedrock grid was subtracted from the surface grid to yield a model of the thickness of basin fill. The grid was then edited to remove areas of negative thickness over bedrock (Huachuca Mountains for example). A contoured map of the resulting basin-fill thickness is shown in figure 4.

The grid of basin-fill thickness was used to compute a gravity anomaly map (fig. 5) by standard techniques using the program described by Cordell and Henderson (1968) and Phillips and others (1993). A uniform density contrast of 0.4 g/cc was used to compute the effect of the basin fill.

Comparison of the gravity anomaly map predicted by the ADWR structure contour map (fig. 5) with the observed gravity anomaly map (fig. 2) shows that the 3-5 mgal anomaly predicted to be associated with the proposed buried bedrock high in the Nicksville area is not present on the observed gravity anomaly map. The slight basinward convexity of the gravity anomaly in the Nicksville area (fig. 2) is related to the westward offset of the complex interbasin area north of Nicksville relative to the Palominas structural subbasin. Comparison of figures 2 and 5 shows, in addition, that the observed gravity anomaly in the Palominas subbasin is about four times greater than that predicted by the ADWR map -- about 26 mgal as opposed to about 6 mgal). This corresponds to a depth of about 2,300 m as opposed to about 500 m.

Well Data An evaluation was made of drillers' logs of thirteen water wells in the vicinity of the postulated area of relatively shallow bedrock near Nicksville. Figure 1 shows the location of the wells, the elevation of the top of the bedrock surface for the wells that apparently penetrated bedrock, and the elevation at the bottom of the hole for those wells that were interpreted not to have reached bedrock. These data, in addition to well location number (see Appendix for explanation of well location numbering system), topographic quadrangle map name, and drillers' bedrock lithology, are given in tabular form in table 1.

Contour lines drawn on the bedrock surface as constrained by these wells indicate that, adjacent to the Huachuca Mountains, the bedrock surface slopes uniformly northeastward at an angle of about 3° (fig. 1). This is in general agreement with the shape and slope of the bedrock surface in this area as inferred from the gravity anomaly data shown in map 1. The well data provide no indication of a northeast-trending area of shallow bedrock.

The chief reason for the differing interpretations of bedrock topography (this report and the ADWR draft map) based on the same well data is mislocation of wells. For example, the well driller's report of one of the key wells was found to have two locations given for the same well (D(23-21)19dad and D(23-21)9dad). The section 19 location was assumed to be the correct one because this location is immediately adjacent to the foot of the Huachuca Mountains and,

Table 1. Locations of wells and elevations of bedrock beneath basin-fill sediments based on interpretation of drillers' logs for selected wells in the vicinity of Nicksville. The well locations are plotted on figure 1. Elevations and depths are in feet.

Well Location	7.5' quadrangle	Surface elevation	Bedrock elevation	Depth to bedrock[1]	Bedrock lithology
D(22-22)17bcd	Lewis Spring	4,095	3,220	875	black lava
D(23-20) 1dbd	Miller Peak	4,865	4,755	110	granite
D(23-21) 2dab	Nicksville	4,380	4,145	235	granite
D(23-21) 3ddd	Nicksville	4,455	4,100	(355)	rock
D(23-21) 5cab	Nicksville	4,635	4,514	(121)	rock
D(23-21) 7caa	Miller Peak	4,800	4,775	25	granite
D(23-21) 7dad	Nicksville	4,740	4,540	200	granite
D(23-21) 7dda	Nicksville	4,760	4,550	210	granite
D(23-21) 8bdd	Nicksville	4,674	4,479	195	granite
D(23-21) 8dbc	Nicksville	4,680	4,402	278	granite
D(23-21)17ccc	Nicksville	4,855	4,755	100	granite
D(23-21)19dad	Nicksville	4,900	4,895	5	granite
D(23-22)17cad	Nicksville	4,280	3,080	(1,200)	conglomerate
D(24-21)11cab[2]	Hereford SW	4,505	3,490	(1,015)	alluvium

[1]Parentheses indicate well did not reach bedrock.

[2]Well location and elevation estimated from location plotted in Drewes (1980).

according to the driller's log, decomposed granite was penetrated 5 ft below the surface. The interpretation of relatively shallow bedrock near Nicksville was based in part on the section 9 location of this well.

RECOMMENDATIONS FOR CONTINUING WORK

Geophysical Studies Continuing geophysical work should include (1) acquiring more gravity stations in areas of sparse coverage, (2) acquisition of truck-borne magnetometer data, (3) basin configuration analysis based on both gravity and magnetic anomaly data, (4) additional sampling of representative types of bedrock for density and magnetic susceptibility measurements, and (5) digitizing geophysical logs of density from boreholes in the Fort Huachuca area.

Additional gravity stations should be acquired in areas of sparse coverage, especially in the area between the road through Palominas (Arizona Route 92) and the international border, and in the Huachuca and Mule Mountains. These areas do not have adequate coverage to define the local gravity anomaly field needed to determine the regional anomaly field, which in turn defines the edges of the San Pedro basin anomaly.

Magnetic field profiles should be obtained along selected roads in order to provide both magnetic and gravity anomaly field definition to model the thickness of basin fill. Use of magnetic data in the inversion will help delineate mid-Tertiary and Mesozoic sedimentary units (Pantano Formation, Glance Conglomerate, for example) from upper Tertiary basin fill.

Geologic Studies Reconnaissance geologic mapping of the upper San Pedro Valley should be a priority. The focus of the mapping should be to look for indications of basin structure, such as the fault scarp mapped by Demsey and Pearthree (1994), and to work out the stratigraphic framework of the basin-fill sediments. Analysis of well logs and cuttings will be an important component of the stratigraphic studies.

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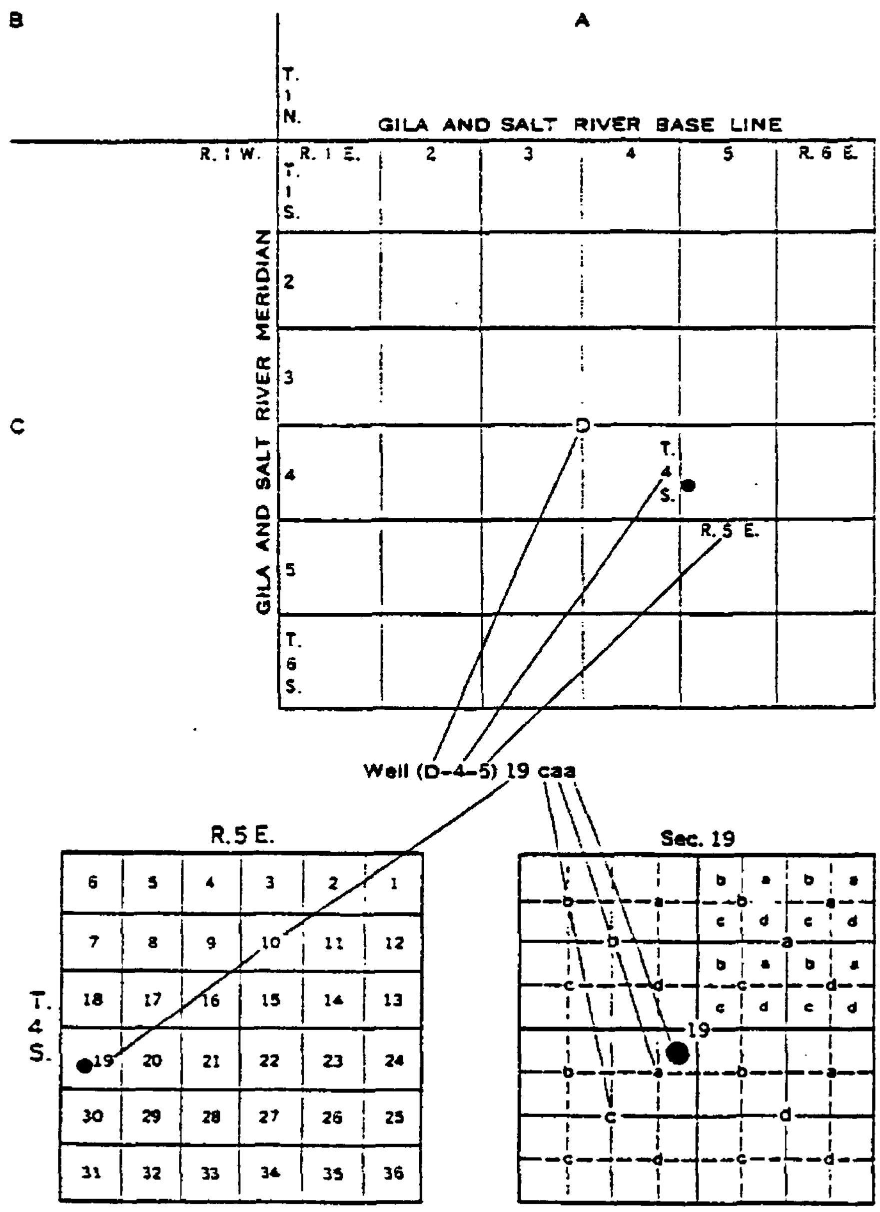
APPENDIX

WELL-NUMBERING SYSTEM

The well numbers used by the U.S. Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in most of Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants. These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land northeast of the point of origin is in A quadrant, that northwest in B quadrant, that southwest in C quadrant, and that southeast in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second a 40-acre tract, and the third a 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known to within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown , well number (D-4-5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 S., R. 5 E. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.



Well-numbering system in Arizona.