NEVADA: THE ELECTRICAL SURFACE

by

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ABSTRACT

Gravity and well logging resistivity data covering the entire surface of the state of Nevada are examined to determine the feasibility of directly detecting conductance values from gravity data acquired in the area.

Thirty-six resistivity well logs, all located in basins, with depths ranging from 3,000 to 14,000 feet, were digitized. Digitized resistivity values for each log were converted to total integral conductance values, as defined by Maillet (1947). Conductance values were corrected for different well elevations and a new value of corrected total conductance was found for each well.

Resistivities of the surface layer to depths up to the basement were calculated at each well. A median value of resistivity for the surface layer was derived and input into a theoretical relationship relating residual gravity to conductance. Through this expression, knowing the residual gravity of the basins of Nevada, it has been possible to plot a contour map of surface conductance covering the entire state.

The result is a surface conductance map of Nevada which showed very high values of conductance in accordance with previous studies and with the regional geology setting of the area.

Nevada highly conductive surface may pose therefore serious problems for magnetotelluric surveys because of its screening effect resulting in a distortion of the magnetotelluric curves.

Neverthless, a good knowledge of high conductance values may help to correct those curves for the caused distortion.

Furthermore the author suggests that the present methodology can be successfully applied in other areas where high surface conductance rocks are encountered, provided that gravity measurements, in terms of Bouguer gravity, be available in order to estimate the corresponding conductance values.

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SECTION 1

Introduction

The area of the state of Nevada has been the object of many geophysical investigations, either aimed at shallow exploration targets or at deep crustal studies, due to its central location in the well studied Basin and Range Province region.

The object of the present work has been aimed at using a combination of gravity and resistivity well logging data to derive a theoretical relation between the gravitational effect of the basins, target of the above mentioned data in the area, and the conductance of basin sediments. The theoretical relation has been used to derive surface conductance values from residual gravity associated to basins.

Using such a theoretical relation, it has been possible, knowing the residual gravity of each investigated basin, to derive values of conductance for the surficial sediments of the same basins at locations without well control.

Furthermore five gravity profiles, stretching across five basins, have been inverted in order to yield a picture of the basement depth and morphology.

The purpose of this study is to present the results and the interpretation of the acquired data, and to synthetize the results in terms of a conductance model of the state of Nevada, pictured through a contoured conductance map.

The analysis of such a map reveals very high values of surface conductance, ranging from 37 to 1,300 Siemens. Such anomalous high values are a key factor in the screening effect influencing electrical soundings probing at great depth.

The study furnishes a good estimate of the surface conductance parameter, allowing to correct the magnetotelluric sounding curves carried out in the area, as will be described in Section Two.

SECTION 2

The Effect of High Surface Conductance on Electrical Geophysics Methods

The electrical conductivity of the Earth rocks is a parameter which is affected mainly by two factors: changes in the water content of a rock, and variations in temperature.

Most of the existing rocks and minerals are non-conductive in dry conditions; neverthless they often retain in their pores or fractures a certain amount of water where some salts may be diluted, acquiring therefore a certain type of conductivity named ionic. That conductivity is mainly influenced by the amount and chemistry of retained water, by the nature of the electrolytes, and by the rock water saturation.

Furthermore a key factor in controlling rocks conductivity is played by the geometrical distribution of pores.

An empirical expression widely used to describe such relationship is given by the Archie's law (1942):

$$\sigma_m/\sigma_w = 1/F = a\phi^{-m} \tag{2.1}$$

where σ_m is the bulk conductivity of the rock, σ_w is the conductivity of the electrolyte in the pore structure, ϕ the rock porosity, F the formation factor, a and m are empirically determined parameters. For sedimentary rocks, where the pore space is the volume left over between grains, values for the two parameters are a=0.6-1, m=1.6-2.

For crystalline rocks, where the pore space is represented by microfractures and joints, reasonable values are a=1.4-2, m=1.3-1.6.

Even rocks which do not retain pore water show a conductivity defined by the Stefan Boltzman law:

$$\sigma = \sigma_0 e^{-E/KT} \tag{2.2}$$

where σ is the rock conductivity, σ_0 the conductivity at a reference temperature, T the absolute temperature, K the Boltzman constant, E is the rock activation energy.

Such relationship shows that rocks at high temperatures have low conductivity values.

Numerous studies on the conductivity of dry rocks have been carried out (Keller, 1989), all showing that at a given temperature a rock conductivity falls in a very wide range extending over two and three orders of magnitude. Also it has been found that the chemical composition of a rock may be an important factor, even though much less important than temperature, in the determination of its conductivity (Karlya and Shankland, 1983). Such studies show that silicic compositions seem to lower conductivity compared to rocks of more basic compositions.

Also it has been experimentally proved that melting processes, caused by abnormally high temperatures, may contribute to increase the rock conductivity. In such a case the conductivity of the molten rock is affected by its composition and mainly by the gases in solution. Its values for basic and ultrabasic rocks have been found in the range from 1 to 100 S/m (Shankland and Waff, 1977).

Given these theoretical premises as a background introduction, let us consider that many geophysical methods have been applied to study the Earth conductivity. They include direct measurements made in wells to depths up to 8 Km, and indirect geophysical measurements. The last ones include direct current resistivity methods mainly used to explore sedimentary basins and the upper parts of crystalline basements, while magnetotelluric and deep geomagnetic soundings have been used to probe the conductivity at crust and mantle depths.

The results of the application of these methodologies have allowed to divide the Earth in five zones with respect to the parameter conductivity. These zones from the surface are: (Keller, 1989)

1) A zone of surface rocks containing water and therefore very conductive to depths ranging from the Earth surface to a few tens of Kilometers.
2) A zone of highly resistive crystalline rocks, at dry and cool conditions. The depths of this resistive zone range from 10 Km in unstable areas to several hundred Kilometers in cold stable areas.
3) A zone of high conductivity mainly due to conduction mechanisms.

4) and 5) These are two zones of rapidly increasing conductivities from a depth between 300 and 700 Km to the base of the mantle.

Also it has been extrapolated that the increasing values of conductivity continue in the core as well, reaching values in the range of 100,000 to 1 million S/m.

The present study is interested in the first shell above described of the area of the state of Nevada, which is part of the Basin and Range Province. Previous studies in that area of Western United States (Keller, 1989) about the properties of the near surface rocks have shown that the conductance of the surface rocks is in the range of 1 to 5,000 S/m.

Such anomalously high values of conductance in the Basin and Range Province at depths up to 10 Km have been geologically interpreted as caused by partial melting phenomena at crustal depths, and by the presence of water either in pores or in fractures. It is the author's opinion that probably the latter factor mainly refers to rocks on the Earth surface, while the former one refers to deeper formations.

The existence of a high conductivity surface layer in the investigated area, significantly interfers with the capability of electrical methods to probe into the deep crust and mantle.

Of all the electrical methods, the one which is most affected by high conductivity surface material is the magnetotelluric method.

Such effect on this method makes it impossible to map the conductance structure at depth, because of this screening effect itself. The main effect of this phenomenon leads to a bias on the vertical shift of a magnetotelluric sounding curve. Figure 2.1 shows a one dimensional apparent resistivity curve for various values of surface material conductance for a profile containing a surface layer of high conductivity, underlain by a basement of infinitely high resistivity, and in turn underlain by lower crust and mantle of increasing high conductance.

The figure well shows that this screening effect reflects itself in the fact that we have a suppression of the insulating part of the profile as well as errors in depths determination.

This effect, caused by high conductance surface material, can be corrected, on the magnetotelluric curves, if a good estimate of the conductance of the surface formations is available.

The aim of the present study is to furnish a method, which utilizes gravity to infer the conductance of surface layers, to be able to correct magnetotelluric sounding curves carried out in the investigated area.

The method can also be used in other areas of the world where this problem arises, providing itself a good tool to correct highly biased magnetotelluric sounding curves.

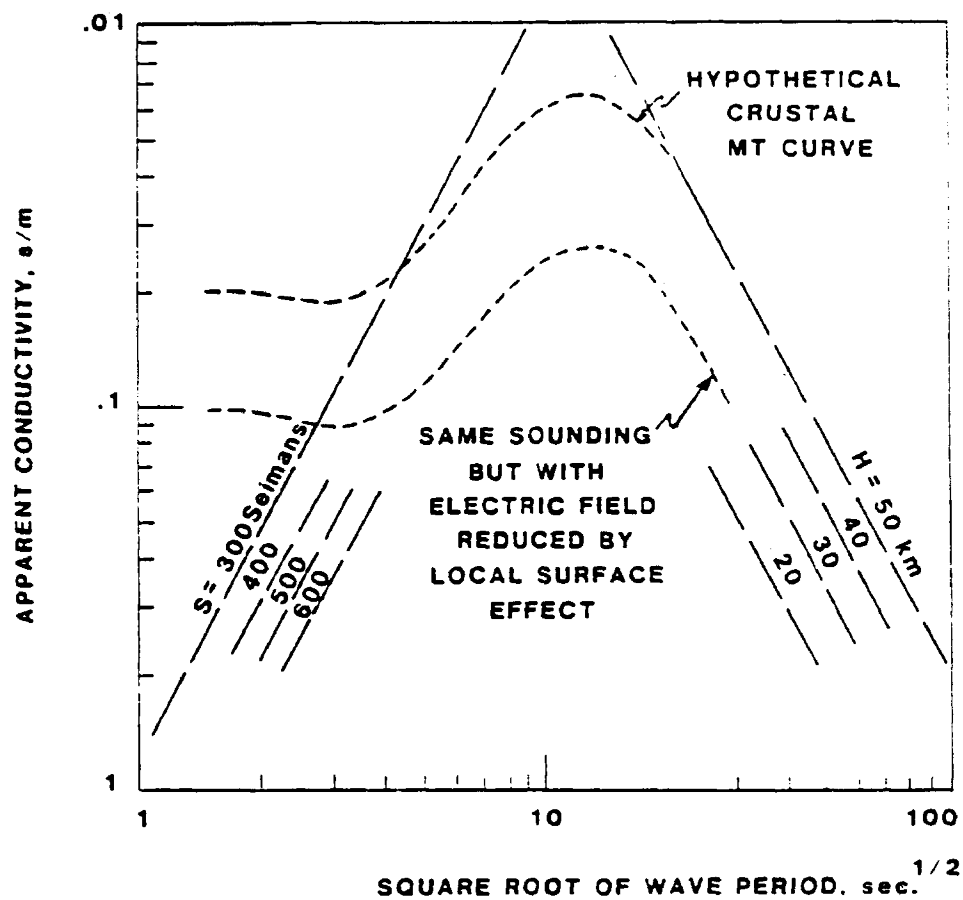


Fig 2.1 Example of the effect of vertical shift of a magnetotelluric sounding due to high conductance surface effects (Keller, 1989)

Correction of Magnetotelluric Sounding Curves Distorted by High Surface Conductance 2.1

A way to correct for the shift of magnetotelluric sounding curves due to high surface conductance and electrical inhomogeneites is described by Hermance (1982). The method uses a finite difference form for simulating the behavior of telluric fields in presence of high conductance or inhomogeneities. It is possible, in this way, to predict the shift of magnetotelluric curves due to the above mentioned factors and to be able to correct the curves for the amount of observed shift.

SECTION 3

The Regional Geology of the Basin and Range Province

Introduction

The area belonging to the state of Nevada, which is the object of the present thesis, is part of a region of the Western United States called Basin and Range Province.

The physiography of the vast area, as illustrated in figure 3.1, is one of modelled and partially buried fault bounded blocks that has been produced by the extension of the region during late Cenozoic time. The distribution of Cenozoic normal faults is pictured in figure 3.2, as well as the distribution of earthquakes in the area that Atwater (1970) called "a wide soft zone accomodating oblique divergence between the Pacific and North American plates", in figure 3.3. The effect of movements along the normal faults leads to a crustal extension oriented WNW-ESE, although the actual motion is quite variable from fault to fault.

The fault distribution does not seem to affect the unextended Colorado Plateau. Some authors believe that the relative motion between the Plateau and the faulted Province may be explained by a component of right-lateral strike slip along the southern Plateau border.

Recent geophysical studies of the area have shown similarities between the Province and regions of past or present extension. Such evidences include a

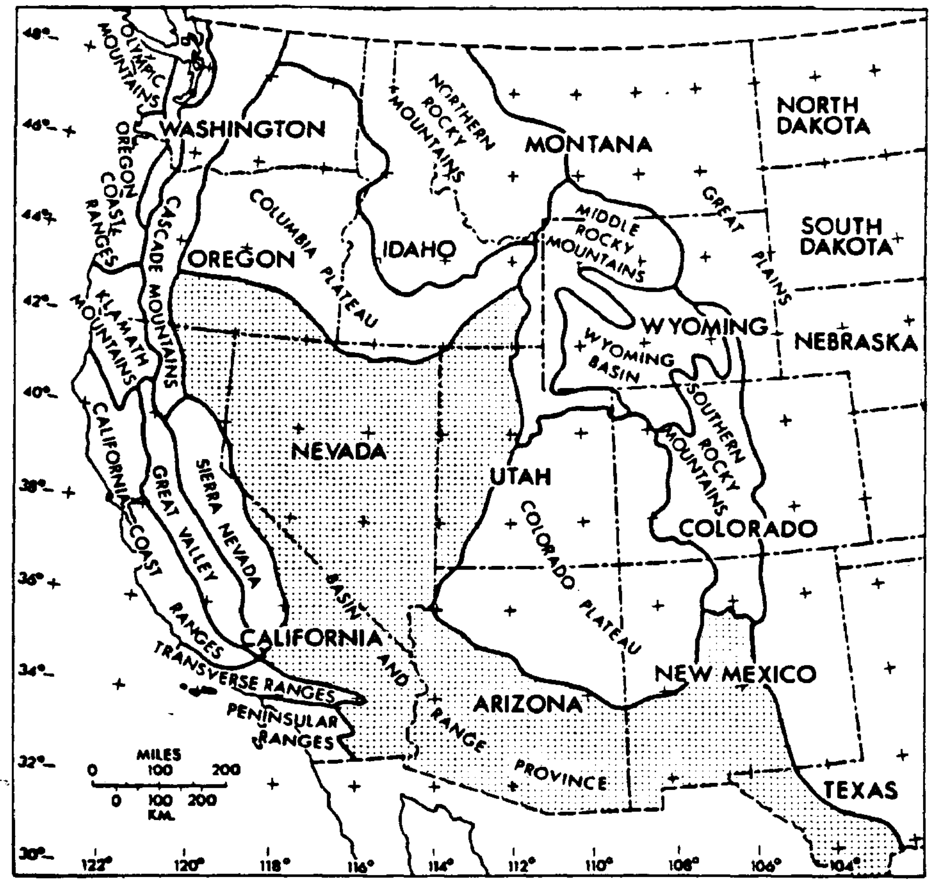


Fig 3.1 Physiography of the Western United States (Fenneman, 1946)

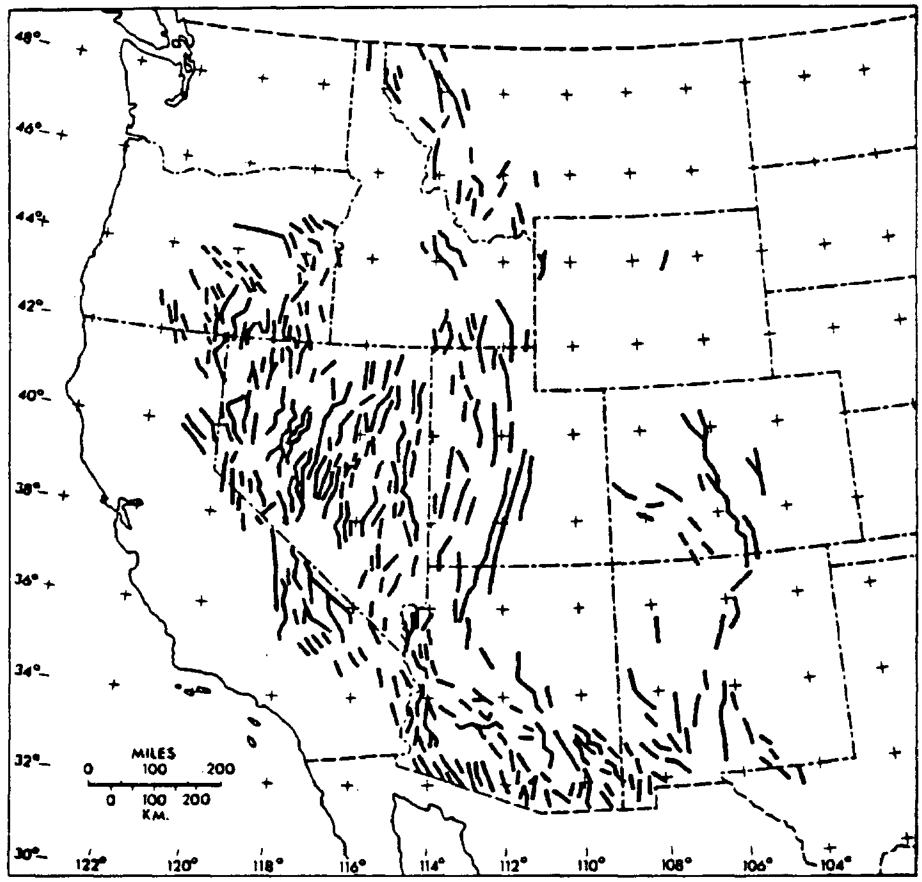


Fig 3.2 Distribution of late Cenozoic normal faults in the Western United States (Gilluly, 1963)

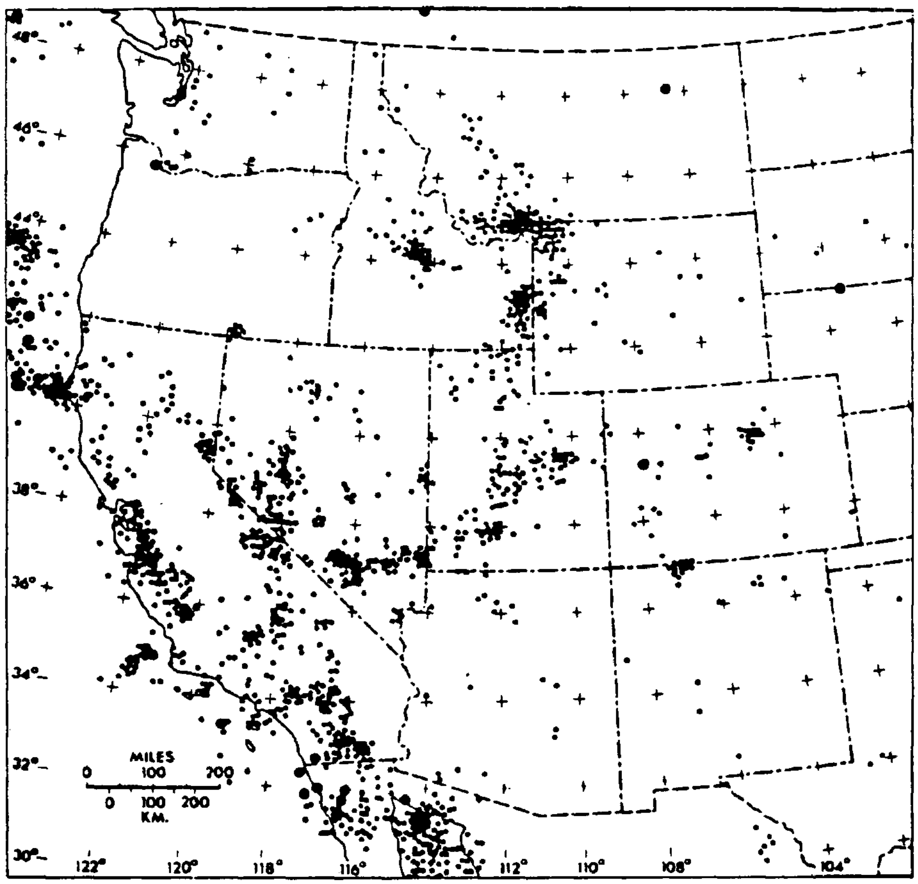


Fig. 3.3 Distribution of earthquakes epicenters in Western United States for a period 1961-70 (Burke, 1974)

high heat flow and widespread volcanism, like the Rift Valley in Africa or the Rhine Graben in Europe. Some authors (Sclater and Francheteau, 1970) have compared the previously mentioned occurrences with the high altitude of the entire Province, relating it to the thermically expanded ocean ridges. And like ocean ridges, other studies have shown a thin crust and low mantle velocity.

However, as far as much of the understanding we have about the region comes from analogy to other geologically similar parts of the world, we cannot discover to what extent earlier geologic and tectonic events have preordained the pattern of actual faulting. The most accepted theory in the scientific community is that an earlier subducting plate at the western margin of North America is still responsible for what we now observe in the Basin and Range Province.

Crust and Mantle Structure 3.1

The most important information about the deep crust and mantle of the region comes from seismic refraction data.

Such data have shown an anomalous thin continental crust (Pakiser 1963, Prodehl 1970) for such an elevated region, low velocity of primary waves, in the order of 7.6-7.8 Km/sec at shallow depths. These waves are also called P_n waves and are those travelling in the uppermost mantle below the Mohorovicic discontinuity. Figure 3.4 shows the crustal thickness in the area

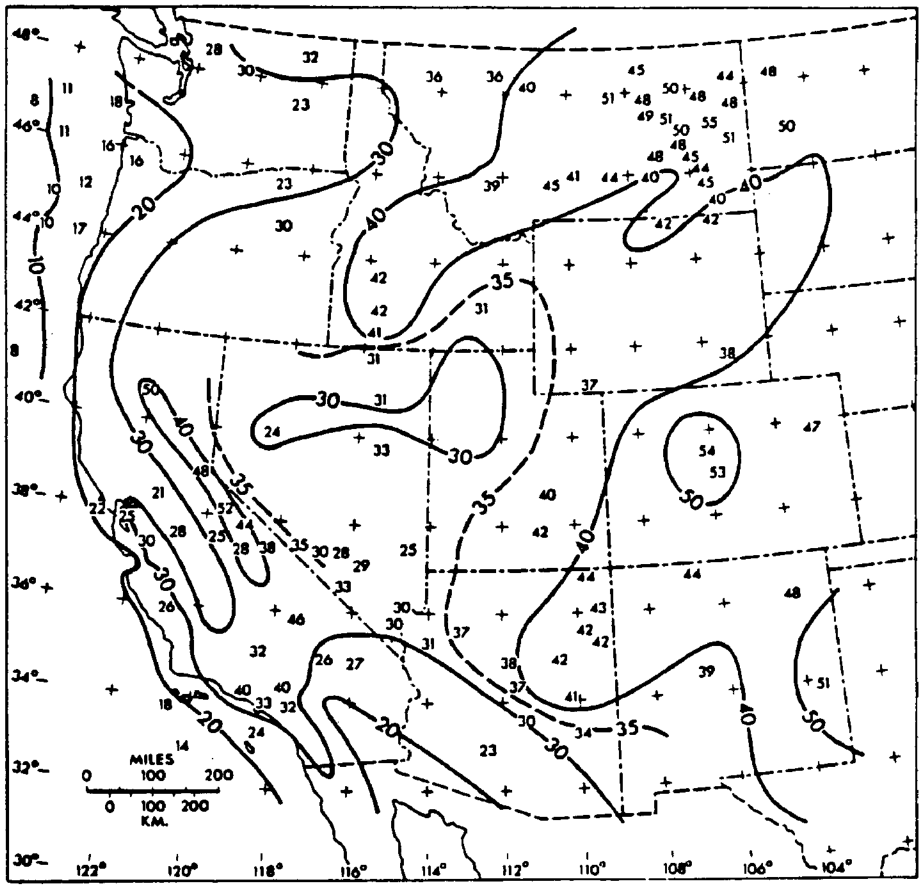


Fig 3.4 Contour map of crustal thichkness (Km) based on seismic refraction data (Burke, 1974)

as derived by seismic data. Gravity data have supplied evidence that most of the isostatic support for the Basin and Range Province is in the anomalous upper mantle which plays an important role in any tectonic model of the area. Isostatic gravity anomalies, in figure 3.5, show that most of the area is deficient in mass, being the average anomaly about -10 mgal.

Other studies have also shown a well defined upper mantle low velocity zone (LVZ) for both primary and secondary waves. The low velocity zone seems to be 100 Km thick and beginning at the top of the mantle and coincident with the anomalous upper mantle (Archambeau et al., 1969).

Extension Characteristics 3.2

The focal mechanisms of local earthquakes show a consistent direction of continuing extension. Focal solutions also show predominantly normal faulting (Scholz, 1971) with extension direction ranging from E-W to NW-SE. The inception of the Basin and Range faulting over Nevada is dated at 15 to 17 million years (Noble, 1972).

The pattern of rupture is of rhomboid type and is common to other regions where extension phenomena are present. Explanations on the shape of the pattern are not well founded, but hypotheses include change in stress system, influence of earlier structure and anisotropy in crustal rock properties.

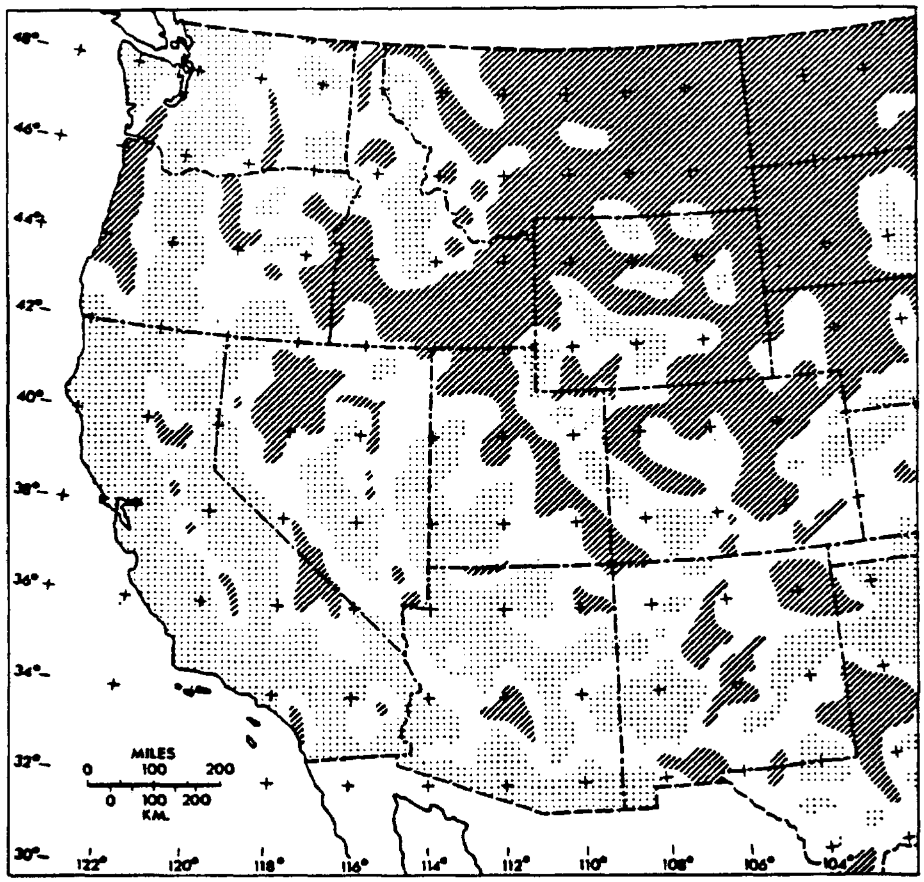


Fig 3.5 Regional isostatic gravity anomalies in the Western United States (Wollard, 1972)

Heat Flow Data 3.3

Anomalously high heat flow values characterize the entire area, as pictured in figure 3.6. Heat flow values greater than 2 HFU (Heat Flow Unit, $\mu cal\ cm^{-2}\ sec^{-1}$) are common in the Basin and Range Province. Recent studies (Roy et al., 1972) have shown linear relation between heat flow values and the radioactive heat production of surface rocks in plutonic areas.

Crustal temperature profiles, based on these studies, have determined that at depths of 30 Km the temperature is in the range of 700°-1000° C. Such high anomalous temperatures, compared to those characterizing the eastern United States, may reach the melting range for granite in the crust, and that of basalt rocks in the upper mantle.

The association of such high temperatures with a widespread volcanism has suggested the generally accepted hypothesis that partial melting phenomena are responsible for the thinning of lithosphere and for shallow low velocity zones in the astenosphere of the region.

Magnetic and Electrical Anomalies 3.4

Magnetic and electrical anomalies support the evidence of an anomalous hot upper mantle. Zietz (1969) showed that long wavelength magnetic anomalies are absent, suggesting the fact that crust and mantle rocks be above the Curie point of 578° C for magnetite.

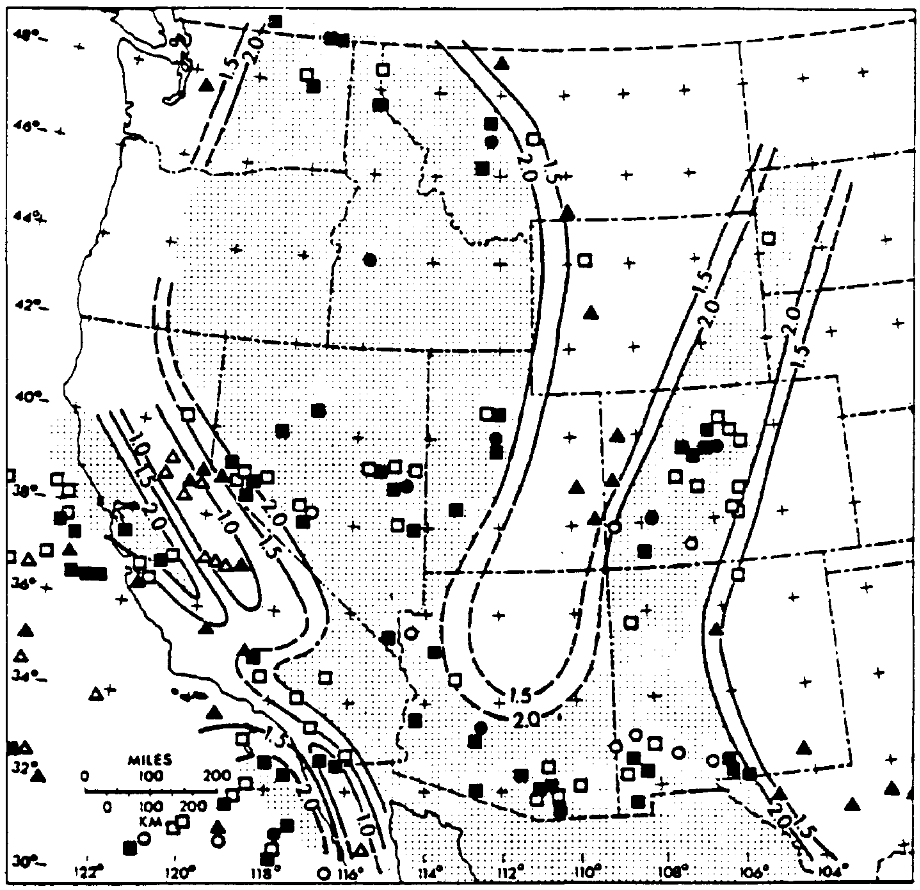


Fig 3.6 Contour map of heat flow (μcal cm^{-2} sec^{-1}) in Western United States (Roy et. al., 1972)

Electrical anomalies in conductivity were measured by Porath and Gough (1971) studying the geomagnetic fluctuations. Such anomalies are well characterized by changes in depth to a half space of conductance of 0.2 mho. The top of the conductor appears to be represented by the 1500° C isotherm, while its depths show wide range of values in the area.

Tectonic Model and Petrological Relations 3.5

The following petrological relations are of crucial importance in the determination of the general tectonic structure of the Basin and Range Province.

It has been established by Lipman (1972) that before the faulting inception, low and middle Cenozoic volcanoes erupted mainly intermediate composition magmas.

At the beginning of the Cenozoic faulting, a change to basaltic volcanism occurred, beginning in the southeastern part and migrating northwestward (Christiansen and Lipman 1972).

It has also been established that the composition of the mantle before the faulting contained 25 % of eclogite (Mc Getchin and Silver, 1972). The eclogite rock may be a key factor in explaining the late Cenozoic uplift of the entire area, because of its property to convert into gabbro with a volume expansion of 10 % in response to a rise in temperature or decrease in pressure.

As portrayed in the previous subsections, geophysical data can set useful constraints in the determination of the tectonic model of the Basin and Range Province. The most important assessments are in agreement with the following geologig effects: high heat flow values, widespread volcanism, thin continental crust, low mantle velocity, high elevation, absence of long wavelength magnetic anomalies, high electrical conductivity.

Gravity data also portray that observed isostatic anomalies present values that are smaller than those that would be observed if a crustal plate is attenuated by horizontal extension. The gravity simply indicates that near surface extension must be matched by lateral backflows in the mantle (Burke et al., 1974).

The general idea, after considering all the observed phenomena, for a tectonic model of the area is that the thermal effects of a past subduction process are still being felt in the Basin and Range Province.

SECTION 4

The Dar Zarrouk Parameters

The Dar Zarrouk parameters, first introduced by Maillet (1947), are of crucial importance in the theory of electrical soundings and electrical logging, and can be very useful in their interpretation.

For sake of clarity, in the present work, I shall present the theoretical background behind the same parameters. Before actually introducing the above mentioned parameters I shall describe some physical quantities that are important to them.

Microanisotropy 4.1

At the purpose to explain the physical meaning of the concept of microanisotropy, let us consider that many geological formations, especially those containing clay and marls, conduct the electrical current more easily along the strata than in a direction perpendicular to these. Hence two different conductivities may be considered:

A) the longitudinal conductivity parallel to the strata, σ_l

B) the transversal conductivity perpendicular to the strata, σ_t

Also other parameters may be defined as:

C) the average conductivity $\sigma = \sqrt{\sigma_l \sigma_t}$

D) the microanisotropy $\theta = \sqrt{\sigma_l / \sigma_t} > 1$

The concept of microanisotropy, as mathematically described by equation (D), plays a real important role in the equivalence phenomenon, common to all electrical prospecting techniques. It states that if we consider a layer of thickness h and average conductivity σ, and anisotropy θ, this is exactly equivalent, in its outside effects, to an isotropic layer of thickness θ h and conductivity σ. The just described phenomenon leads to consider that it is not possible to discriminate between an underground layer with anisotropy θ, and an equivalent isotropic layer θ times thicker. Therefore this fact leads to great indeterminateness with respect to computation of depth, which can be well defined only if we have a detailed knowledge of the anisotropy factor.

Macro-anisotropy 4.2

Besides the concept of microanisotropy, which is a rock property itself, we have to take into consideration the phenomenon of macro-anisotropy which results of a repeated occurrence of two different lithotypes made up of thin beds. In this case the current will tend to flow more easily in the direction of the strata, utilizing the most conductive beds, rather than perpendicularly. The effect of macro-anisotropy, as explained, is completely similar to the microanisotropy effect, at least in the case when the measuring electrical devices are large compared to the thickness of the considered beds.

In the case of two layers of thickness h_1 and h_2, of conductivities $\sigma_1$and $\sigma_{\ 2}$, it is possible to consider an average longitudinal conductivity σ_t and an average transversal conductivity σ_l using the following equations:

$(h_1 + h_2)\,\sigma_l = h_1\sigma_1 + \sigma_2 h_2$

$(h_1 + h_2)\,/\sigma_t + h_1/\sigma_1 + h_2/\,\sigma_2$

the latter conductivities, namely σ_l, σ_t, are the longitudinal and transverse conductivities of a single bed made up of microanisotropic material of a thickness equal to that of the two layers combined, and offering the same propagation of either longitudinal or transverse current lines. Therefore a definition of the macro-anisotropy factor may be given by the following equation:

$$\theta^2 = \left[\left(h_1\sigma_1 + h_2\,\sigma_2\right)\left(h_1/\sigma_1 + h_2/\,\sigma_2\right)\right]/\left(h_1 + h_2\right)^2$$

The Dar Zarrouk Variable and the Dar Zarrouk Function

If we consider the relation between a micro-anisotropic and the corresponding isotropic layer, the following quantities are constant:

$h(\theta/\sigma) = h\,(1/\sigma)$

$h(\theta\sigma) = (\theta h)\sigma$

namely the product of the thickness by the transverse resistivity and the product of the thickness by the longitudinal conductivity. As seen before, the same holds true for the correspondence between macroanisotropic layer and the equivalent micro-anisotropic formation.

Therefore the two products, above described, are capable of characterize a geological layer better than any other parameter, and we are led to consider the following integrals:

$R(z)= \sum_{z}^{z=0} \theta(z)/\sigma(z)$ called Dar Zarrouk variable or transverse unit resistance.

$C(z)=\sum_{z}^{z=0} \theta(z)\sigma(z)$ called Dar Zarrouk function or longitudinal unit conductance.

If we consider the geologic model in figure 4.1, R(z) measures the resistance to the lines of current perpendicular to the strata, while C(z) the conductance offered to the lines parallel to the strata, θ is the micro-anisotropy factor increased by macro-anisotropy caused by very minute layers.

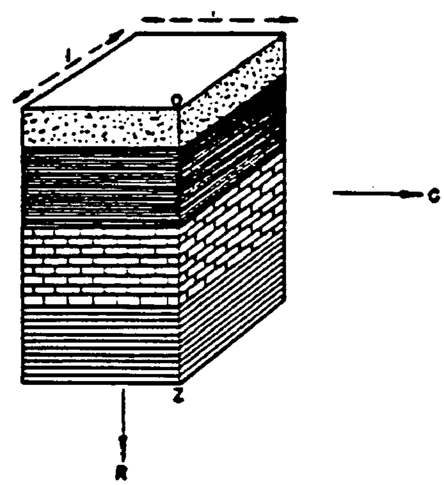


Fig 4.1 Illustration for a transversal unit resistance and longitudinal unit conductance (Maillet, 1947)

SECTION 5

The Use of Gravity to Infer Conductance

Experimental considerations have shown that it is possible to correlate the gravitational attraction of an infinite slab of known thickness and density to the electrical conductance parameter. For this purpose let us introduce the following equation:

$$P_b = (1 - \phi)P_m + \phi P_f \qquad (5.1)$$

where P_b is the bulk density of a rock, ϕ is the porosity, P_m the matrix density of the rock, P_f the fluid density, which is equal to 1 for water.

It is possible to write equation (5.1) in the following way:

$$P_b = (1 - \phi)\,P_m + \phi \qquad (5.2)$$

and also

$$P_b = -\,\phi(P_m - 1) \qquad (5.3)$$

Let us introduce now the gravitational attraction of a infinite slab:

$$\Delta G = 2\Pi G P_b h \qquad (5.4)$$

Where G is the gravitational constant, P_b the density of the slab, h the thickness expressed in meters

Substitution of equation (5.3) into equation (5.4) yields:

$$-\Delta G = 2\Pi G\phi(P_m - 1)h \tag{5.5}$$

Now if we let h = SP, where S is the conductance, P the rock resistivity we can rewrite equation (5.5) in the following way:

$$-\Delta G = \left[2\Pi G\phi(P_m - 1)\right]PS \tag{5.6}$$

Equation (5.6) can also be written as:

$$-\Delta G = aPS \qquad \text{where } a = (2\Pi G\phi(P_m - 1) \tag{5.7}$$

In order to calculate the coefficient a, introduced in equation (5.7), it is necessary to estimate the values of porosity and matrix density which are included in the coefficient a. Typical value of porosity is 0.33 and common value of rock matrix density can be estimated as 2.67gr/cm^3. In this case a = 0.0230966. From equation (5.7) it is possible to derive the conductance parameter from the gravitational attraction of an infinite slab. In fact, we have:

$$S = \frac{1}{aP}\Delta G \tag{5.8}$$

For this relationship the parameter conductance can be calculated if we know the ΔG, a, and P parameters. For the purpose of the present study we can consider the parameter ΔG as a good first approximation to the gravitational attraction of a basin, and hence through equation (5.8), knowing the residual gravity of each investigated basin, it is feasible to calculate the corresponding theoretical conductance.

In order to be able to derive the conductance parameter, however, we have to know the rock resistivity parameter. This can be calculated at each well location, representing the resistivity of the basin sediments up to basement depths. A median value of resistivity can thus be calculated and input in equation (5.8), as will be described in Section Six.

Thus, the coefficient $\frac{1}{aP}$ can be computed and therefore conductance can be derived from the residual gravity of each basin.

SECTION 6

Data Analysis

Introduction

Resistivity well logging and gravity measurements are the two geophysical methods used, in the present work, for the purpose of deriving a theoretical relation between the residual gravity of the basins of the state of Nevada and the electrical conductance derived at some well locations inside such basins, and to check the practical validity of the theoretical expression (5.8) introduced in Section Five.

Furthermore the same data are utilized to infer the parameter conductance from the residual gravity for each basin where no well is available.

Resistivity Logging Data 6.1

Introduction

The object of resistivity logging is to estimate the true formation resistivity R_t in order to determine water and hydrocarbon saturations. A major problem in the correct estimation of Rt is that the mud filtrate, used in drilling the well, invades the permeable zone up to a certain horizontal distance from the bore and the apparent resistivity obtained with any kind of device will be somewhat influenced by the invasion profile of the mud resistivity. To prevent to some extent such alteration on the values of true resistivity, resistivity logs, from early days, have consisted of three curves: deep, medium and shallow investigation.

With those three measurements and considering the invasion profile of stepped shape it is possible to obtain corrected measures of the true resistivity.

The above mentioned curves can be subdivided by their radii of investigation: deep (+3 ft), medium (1.5-3 ft), shallow (0.5-1.5 ft), flushed zone (1-6 in).

Therefore the deep curve will read a value of resistivity at a longer horizontal distance from the bore than the medium and shallow curves, being in this way less affected by the invasion profile of the mud filtrate.

Conventional Resistivity Logs 6.2

In conventional resistivity logs, currents are circulated through the geologic formations through a pair of current electrodes and voltages are measured by means of other two electrodes. The recorded voltages, supplied current and geometry provide the resistivity determination. A most important factor allowing the current to circulate is that the measuring sonde must be run in holes containing electrically conductive mud or water.

Two of the most used conventional tools are the normal device and the lateral device, which will be treated thereafter.

For introducing the normal device, let us consider an homogeneous earth model drilled by a borehole containing mud having the same resistivity of the surrounding earth material. Figure 6.1 illustrates the idealized model. The survey current is emitted at electrode A and returns to the electrode B placed at infinity. M is the potential electrode and N is the reference at zero potential.

Such device is called normal device. A generator at the earth surface provides the current to flow, and a voltmeter measures the potential difference between the voltage electrodes. In this way, by measuring the voltage and current intensity values, it is possible to derive a value of resistivity for each reading. In general, since the earth cannot be considered homogeneous, but layered, the values of resistivity obtained in this way are generally referred as apparent resistivity, being a complex average of the true resisivities of the earth.

For the normal device the apparent resistivity is given by:

$$Ra = 4\Pi(AM)(V/i) = Kn(V/i) \tag{6.1}$$

where AM is the vertical distance between these two electrodes, V is the measured voltage between M and N electrodes, i is the current intensity and Kn is the sonde coefficient.

From expression (6.1) it is possible to extract a value for the true resistivity of a layered bed, even though this process is in principle an indeterminate problem. In fact different combinations of true resistivity, borehole diameter, invasion diameter and bed thickness can produce the same values of apparent

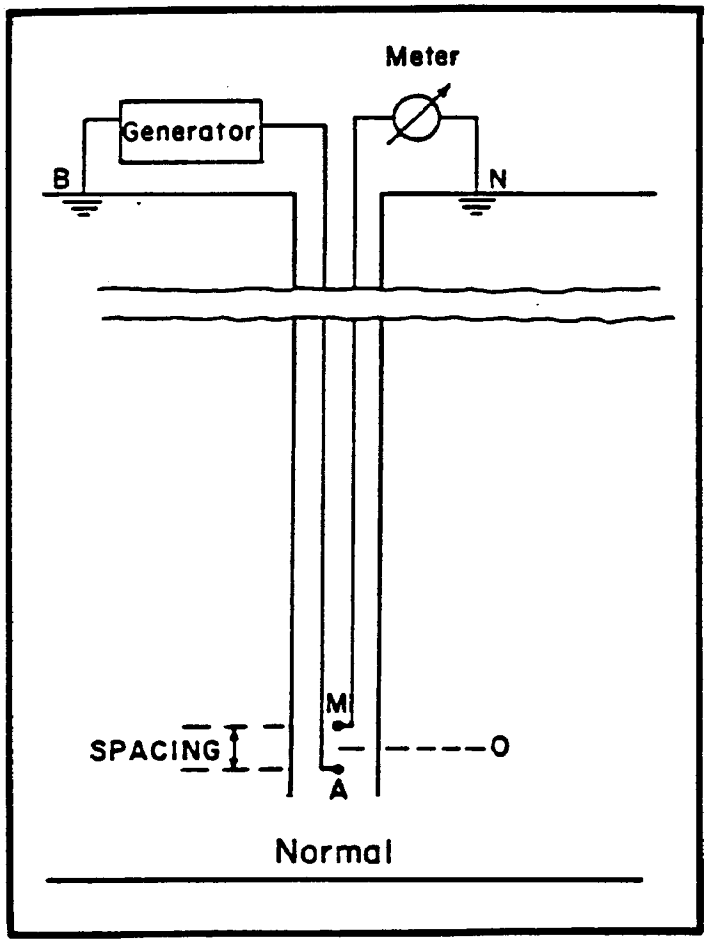


Fig 6.1 Normal array (Schlumberger, 1974)

resistivity. Thus, it usually requires additional measurements by means of other sondes, to measure true resistivity.

The normal device usually uses two AM spacings of 5-20 in., referred as short normal, and 20-84 in., referred as long normal, depending on the desired vertical resolution and lateral depth of investigation.

The Lateral Device

Another tool which originated from the normal device is the lateral device. The lateral device, in figure 6.2, places the voltage electrodes M and N close together with the current electrode A at distance. Such array disposition allows detection of thin resistive beds between two more conductive beds. In a similar way, an apparent resistivity function, as derived for the normal device, can be derived for the lateral device too:

$$Ra=4\Pi\{[(AM)(AN)]/(MN)\}V/i=Kl\ (V)/i \tag{6.2}$$

where AM, AN, MN are the vertical distances between these electrodes, V is the measured voltage, i is the current intensity, Kl is the lateral sonde coefficient.

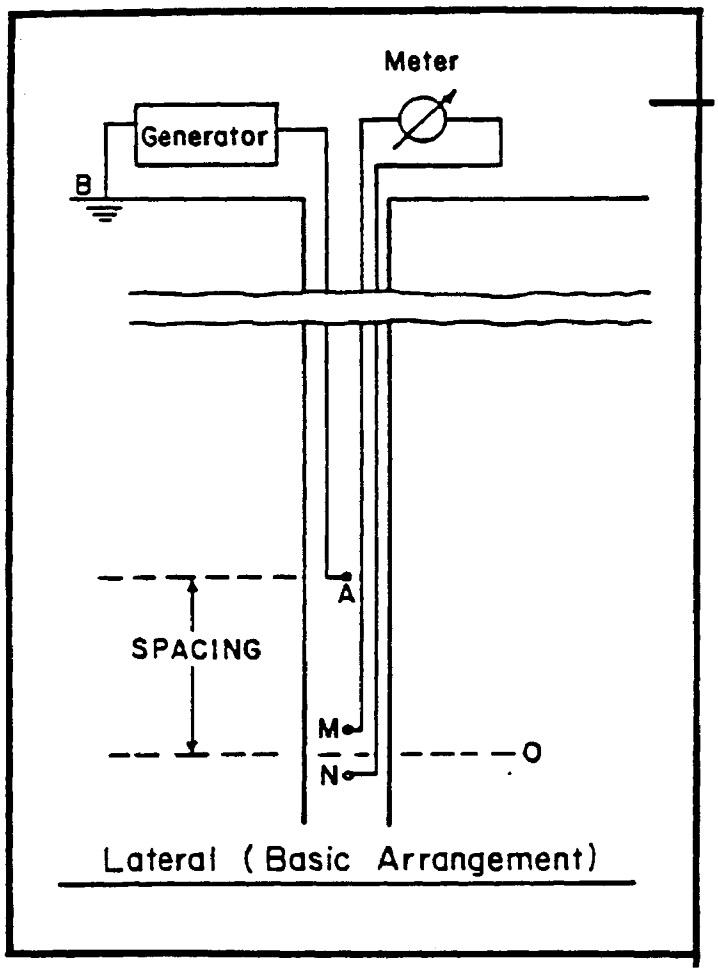


Fig 6.2 Lateral array (Schlumberger, 1974)

Focusing Electrode Logs 6.3

The previous subsection, describing conventional resistivity logs, shows that such systems can be greatly affected by borehole characteristics and adjacent formations.

Those drawbacks are significantly reduced by a category of tools using focusing currents supplied from special electrodes.

Such a family of devices includes the Lateralogs and the spherically focused logs. Such systems are used for shallow, medium and deep investigations. The devices more apt to measure true resistivity are the lateralog 7 and 3 and dual lateralog, while medium to shallow investigation tool is lateralog 8. For the purpose of the present work only deep investigation tools were used and therefore only these will be described.

The Lateralog 7 and 3

The lateralog 7 device, pictured in figure 6.3, has a center electrode Ao and three pairs of electrodes M1 and M2, M^1 and M^2, and A1 and A2. Each pair of electrodes is symmetrically placed around Ao and are connected to each other by a short-circuit wire.

The tool is set operative through a current Io injected through electrode Ao, and through the injection of a bucking current through electrodes A1 and A2. The potential difference is measured through any of the voltage electrodes Mi and an electrode placed at the ground surface at a large distance. Using a constant Io current, the voltage measured is function of the formation resistivity. Such potential is converted to a value of apparent resistivity, from which true formation resistivity can be extrapolated, through multiplication by a sonde coefficient.

The Lateralog 3 Device

Such tool is almost identical in its field layout to the lateralog 7, except that the presently considered device uses longer electrode separations as portrayed in figure 6.3. As a result this tool provides a better vertical resolution and is more detailed in its results than lateralog 7, being less influenced by borehole parameters.

Dual Lateralog

These devices compensate for the fact that in conventional lateralogs the measuring current has to traverse the invaded zone to reach the undisturbed one, and the final voltage measurement is necassary a combination of effects.

These tools, in figure 6.4, use a second measurement at a different depth of investigation, possibly in the undisturbed zone, in order to have a more precise value of true formation resistivity.

Dual lateralogs are used either for shallow or deeper investigations.

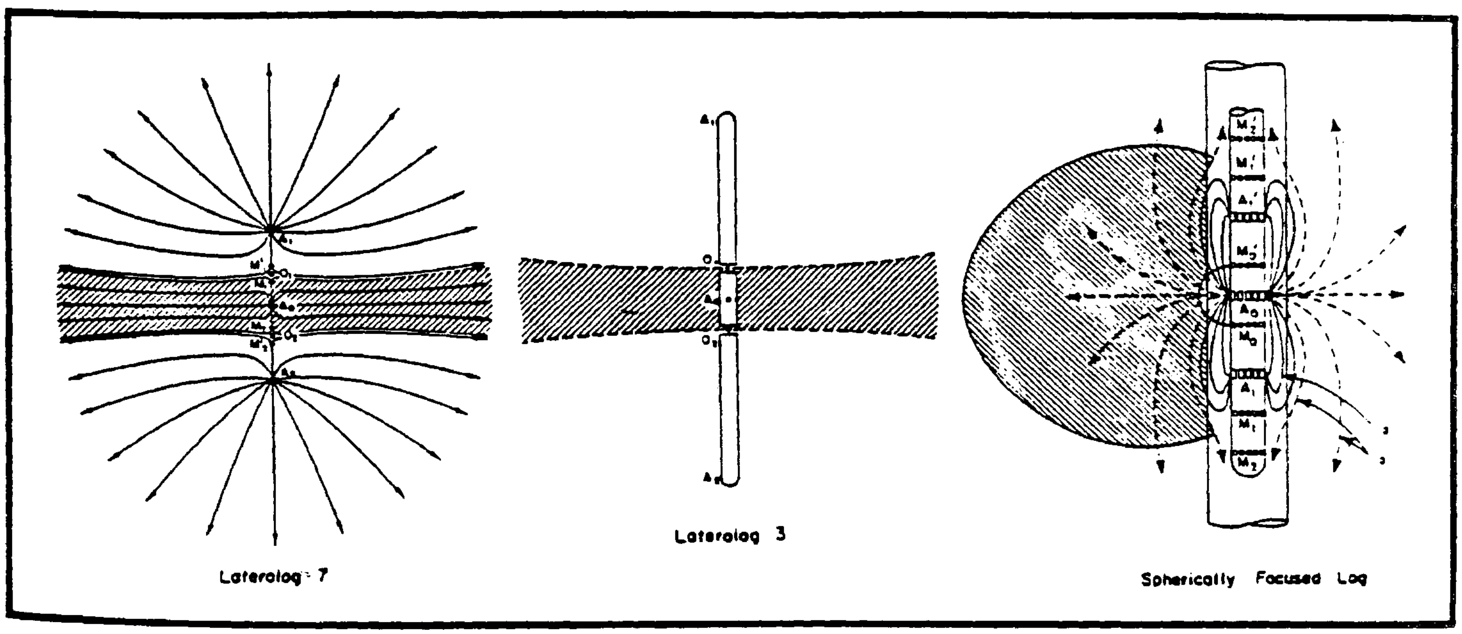


Fig 6.3 Schematic of focusing-electrode devices
(Schlumberger, 1974)

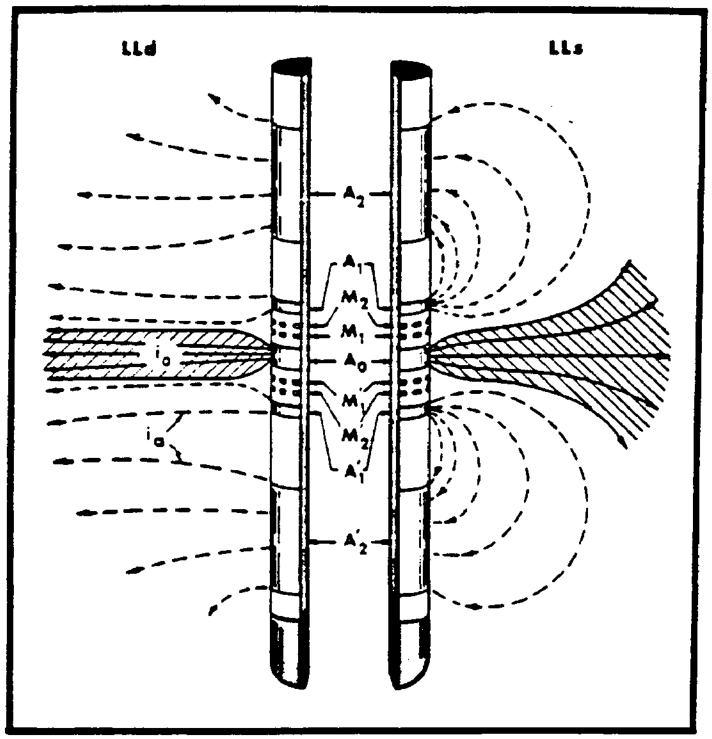


Fig 6.4 Schematic of the dual lateralog (Schlumberger, 1974)

Spherically Focused Logs

While normal resistivity tools rely on the fact that the current radiation is equal in all directions, the spherically focused logs use focusing currents to enforce a spherical shape on the equipotential surfaces over a range of bore variables.

The effect is that all borehole effects, present in other devices, are removed from the measurements.

Log Digitizing

A total of thirty-six resistivity well logs, all located in basins as portrayed in figure 6.5, have been digitized using a sample interval of ten feet. The average depth of each well is in the range between 3,000 and 14,000 feet. Such a depth range provide coverage for all basin sediments in terms of true resistivity parameter, while the deeper logs provide also information about the basement depths. Most of the above considered logs are dual induction or spherically focused logs. A table containing all the data with all characteristics is in Appendix 1.

Particular care has been applied in choosing the resistivity curve, for each log, less influenced by the mud resistivity, whenever this was available. Under these circumstances the author assumes that the digitized values of resistivity fall within an error of ± 5% with respect to the true rock resistivity.

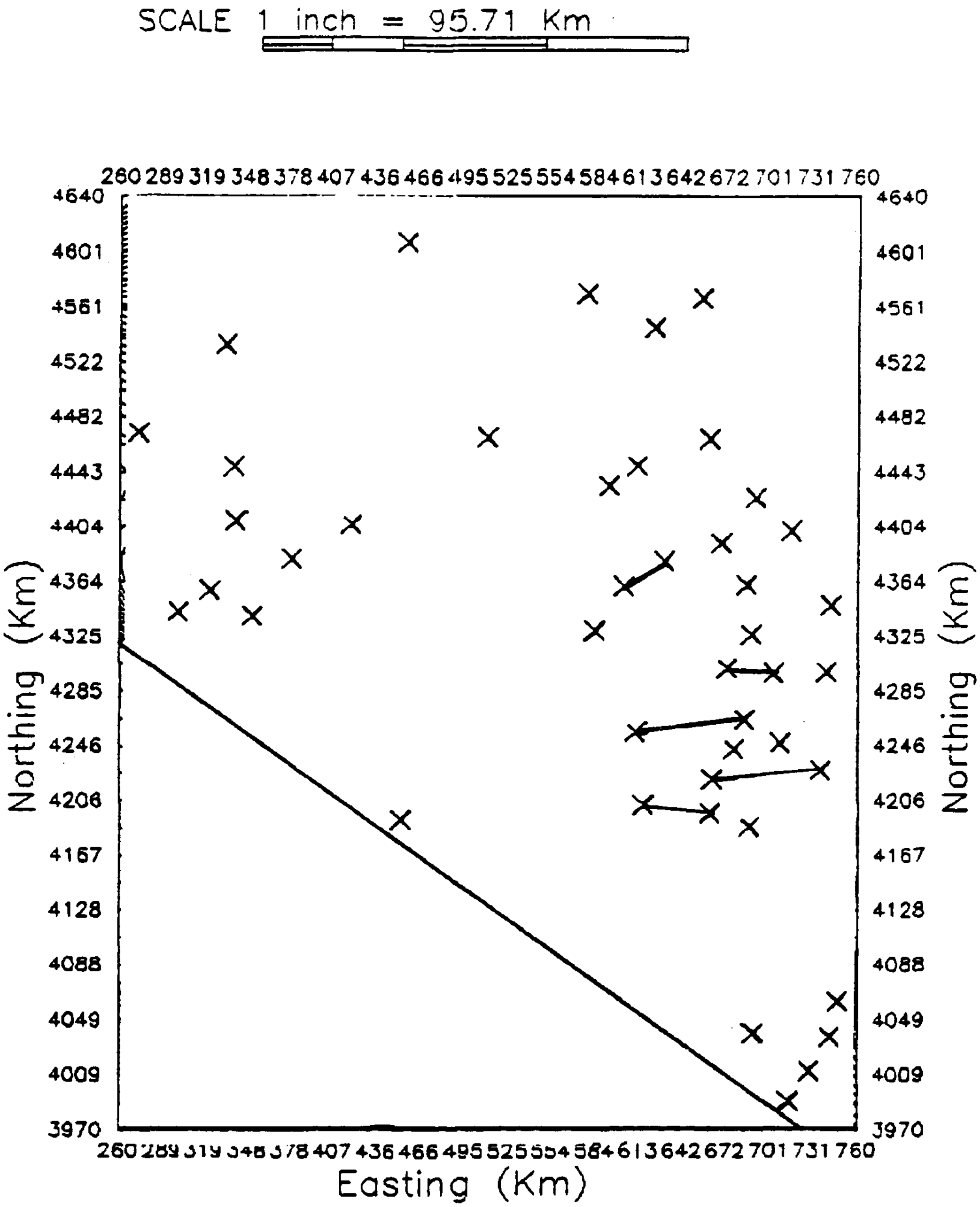


Fig 6.5 Locations of resistivity well logs
X well locations x -- x inverted profiles

Once all data were digitized, a computer program called ELOG (Keller, Appendix 2), has been applied to them in order to calculate the Dar Zarrouk parameters. In particular, the longitudinal conductance parameter (Maillet, 1947), as introduced in Section Four, was calculated and represented in a file as a function of depth for each well. Once obtained, the total conductance values have been corrected by projecting them to the earth surface, since the program computes the conductance from a certain depth for each well, depending on the well elevation itself.

Corrected total conductance values for each well have been obtained, namely representing the conductance values of the basin sediments to depths up to the basement of each basin, measured at different points in different basins.

Using these values of surface conductance and knowing the depth of a basement, observing the behavior of each conductance curve versus depth, it is possible to calculate the resistivity of the surface sediments for each well. In fact, $h = PS$ and $P = h/S$ when P is the resistivity, S the conductance and h the basement depth.

Once obtained, the resistivity values for each well were plotted in the isthogram pictured in figure 6.6. The isthogram, drawn on a semi-logarithmic scale, shows the different ranges of calculated resistivities versus the number of sample values falling within each resistivity range.

From the isthogram a median value of resistivity, P_{median} can be calculated, and it was found to be equal to 1.30 ohm • m, a value which well reflects the high conductance values of the area.

It is the author's opinion that the median resistivity value is the best statistical value of surface resistivity in the investigated area, well reflecting the weight of each range of calculated resistivities.

The knowledge of the resistivity median value allows calculation of the conductance from the residual gravity effect of each basin through equation (5.8).

Gravity Data 6.4

A complete Bouguer gravity map of Nevada has been plotted from previously acquired surveys at scale of 1:2,000,000 and is portrayed in figure 6.7. A second map , at the same scale, has been obtained, in figure 6.8, showing only the Bouguer gravity confined in the basins, deleting therefore the gravity effect due to mountains and general topographic relief.

From the last map, pictured in figure 6.8, it has been possible to derive a residual gravity map showing the gravity associated only to the basins of Nevada. This map will be explained in detail in Section Seven along with its role in the determination of basins conductance from basins residual gravity.

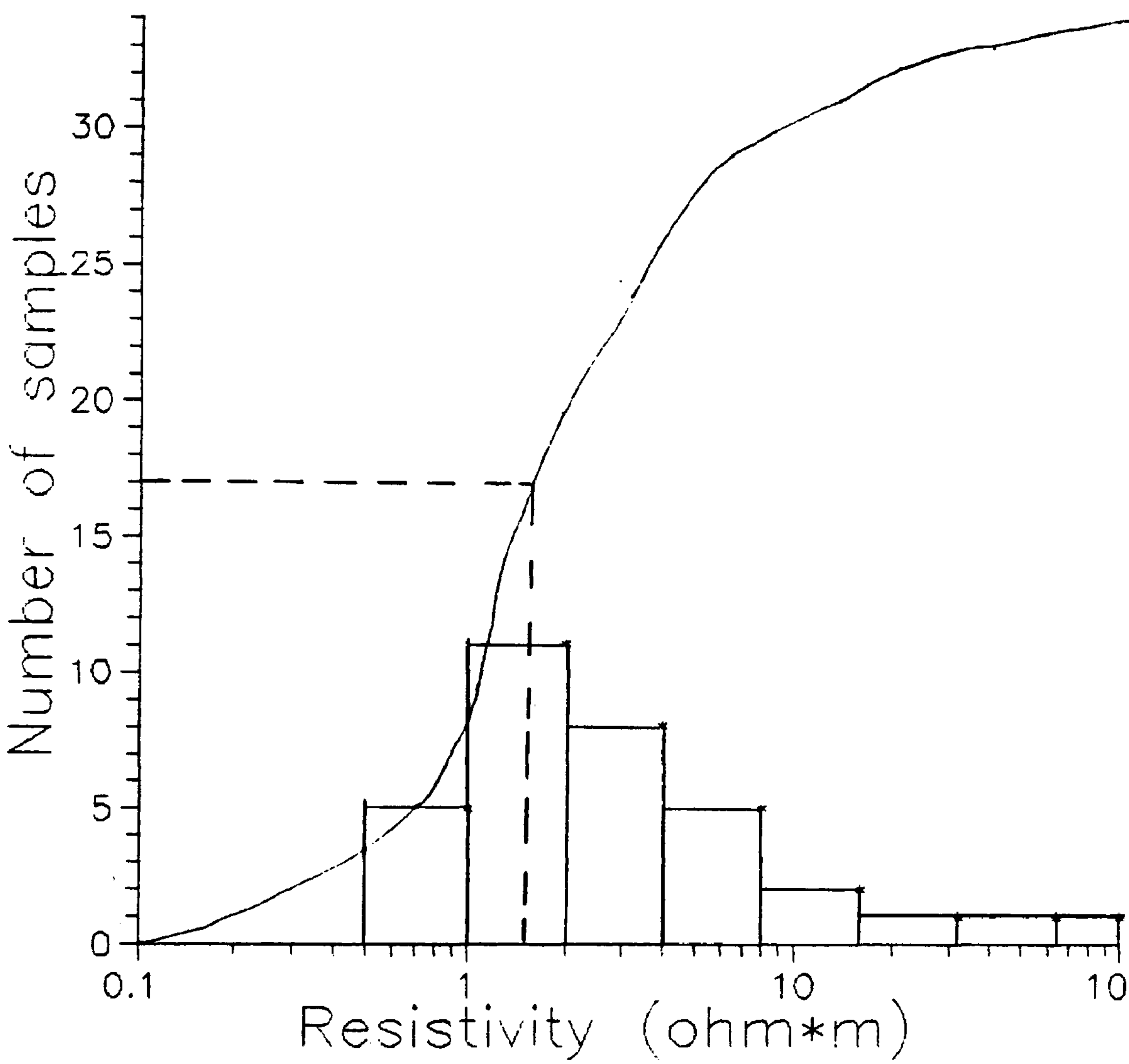


Fig 6.6 Isthogram of resistivities of selected well sites versus number of samples

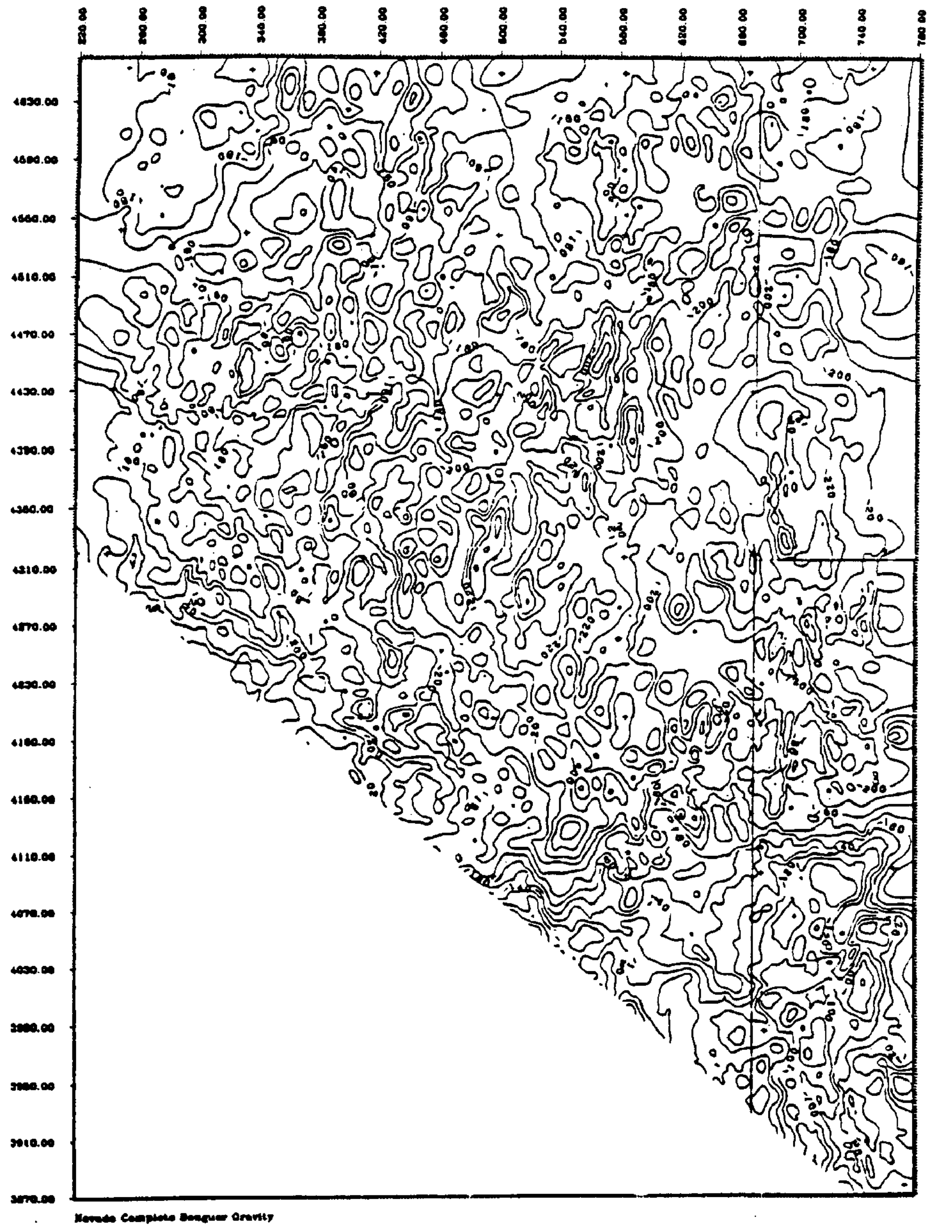


Fig 6.7 Complete Bouguer gravity map of Nevada.
Scale 1:2,000,000 (UTM coordinates)

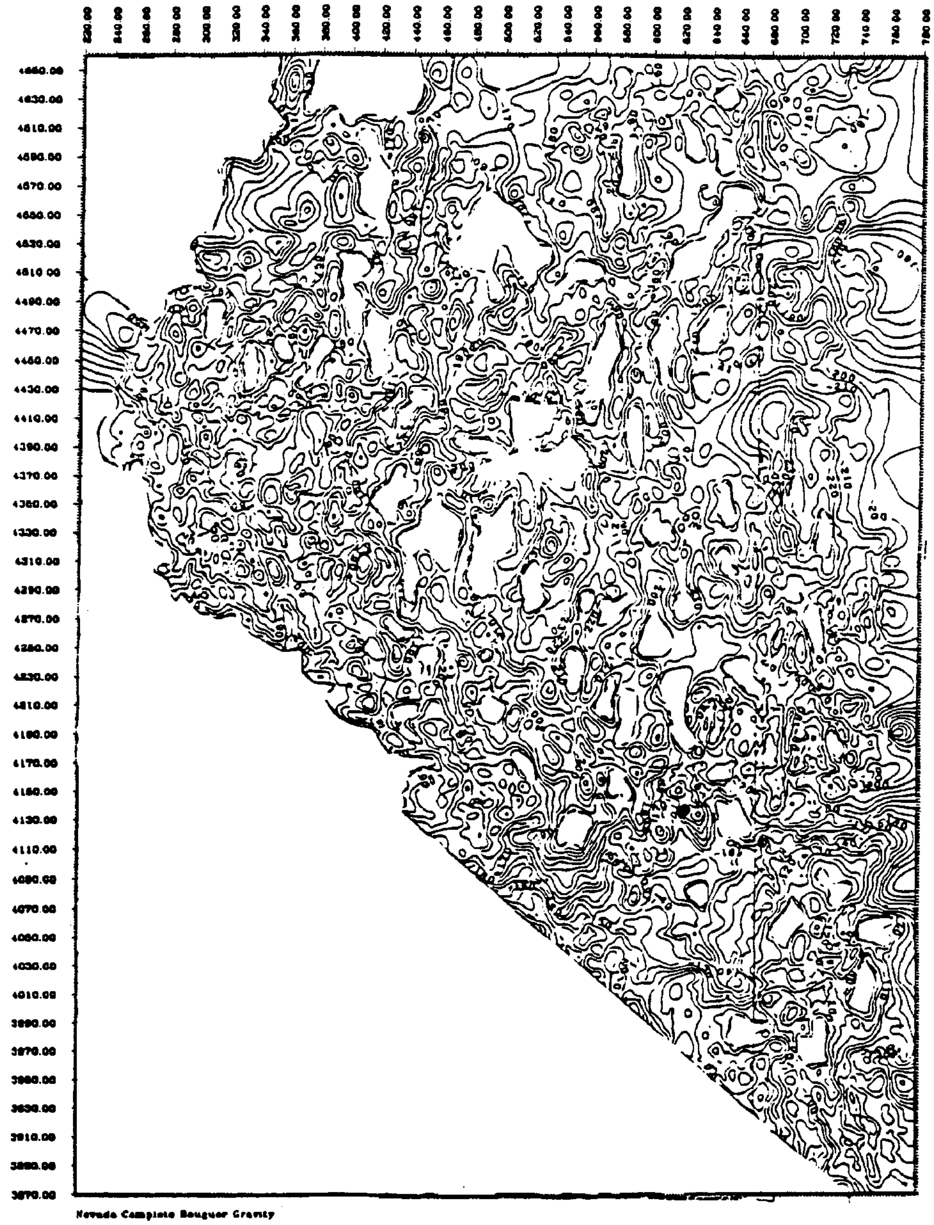


Fig 6.8 Bouguer gravity map of basins.
Scale 1:2,000,000 (UTM coordinates)

Profile Inversion 6.5

Another interest in the gravity data has been to determine the large scale structural trends beneath areas of basin fill. Being such structural trends roughly parallel, a profile inversion program has been used to invert some profiles. The program, written by Crewdson (1976) and subsequently modified by Andersen, uses the rectangular cross section formulas of Morris and Sultzbach (1967).

In the program the basin-fill cross section is approximated by a set of contiguous vertical rectangular strips. In each strip the upper section coincides with the topographic surface, while the lower section defines the basement-fill contact. The strip lengths and depths are estimated by an iterative procedure or may be input as a trial body. The gravity anomaly produced by the so defined trial body is computed and subtracted from the observed values, giving a residual. A constant density for each strip or laterally varying densities may be input, while a single basement density is assumed. The observed gravity profile is assumed to have regularly spaced points in terms of complete Bouguer gravity.

In order to better constrain the profile inversion, at least two depths to the basement should be known.

The five inverted profiles are displayed in figure 6.9 through 6.13 and a summary of the tabulated data are in Appendix 1.

Interpretation 6.6

The profiles considered were inverted using a basement density of 2.67 gr/cm^3 and a basin fill density of 2.00 gr/cm^3 in accordance to previous reports (Crewdson, 1976). Depth to the basement were known at two points in all five profiles. These depths were obtained at well locations interested by the profiles, considering the shape of the conductance curve with depth.

A good agreement was found between the morphology of the residual gravity of each basin, obtained by the program, and the basement valley-fill contact.

Therefore it is possible to calculate, at least qualitatively, the depth and morphology of the basement for each basin not interested by profiles knowing their residual gravity effect.

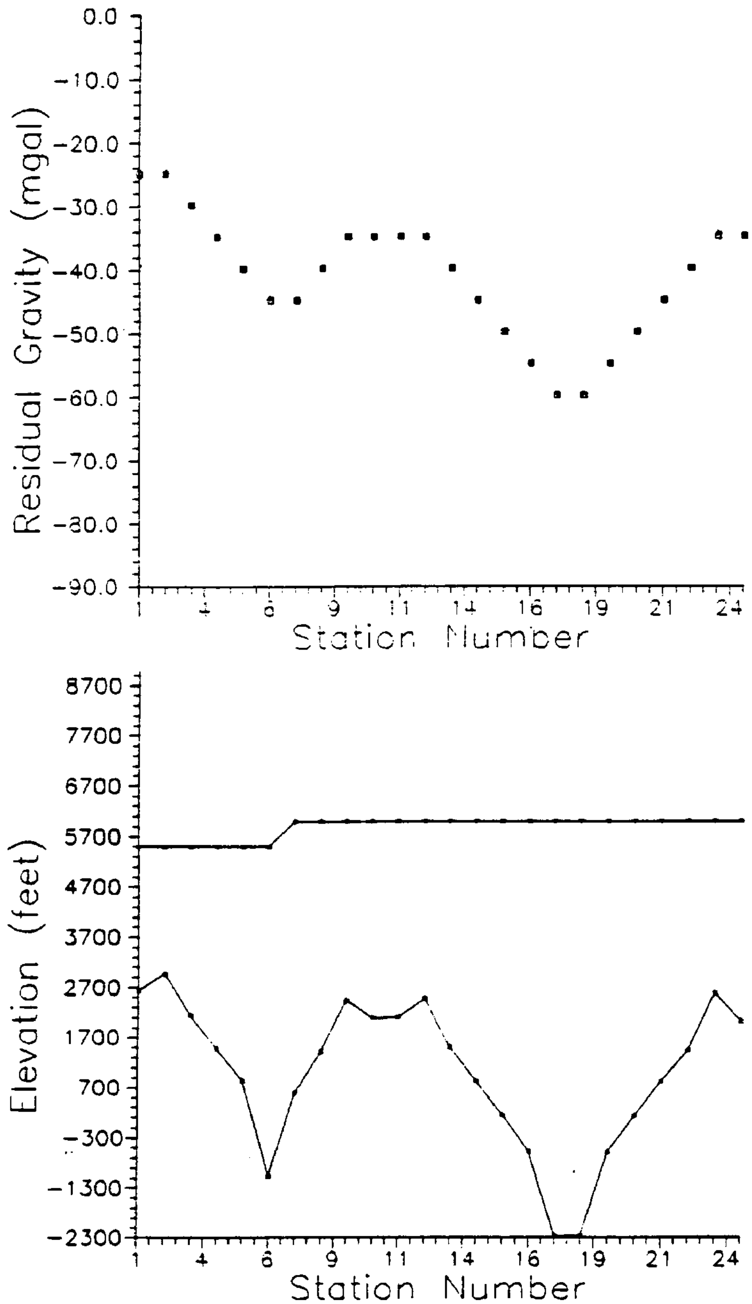


Fig 6.9 Computer inverted profile
Whiter-Amoco Profile
◻ Observed Gravity * Calculated Gravity

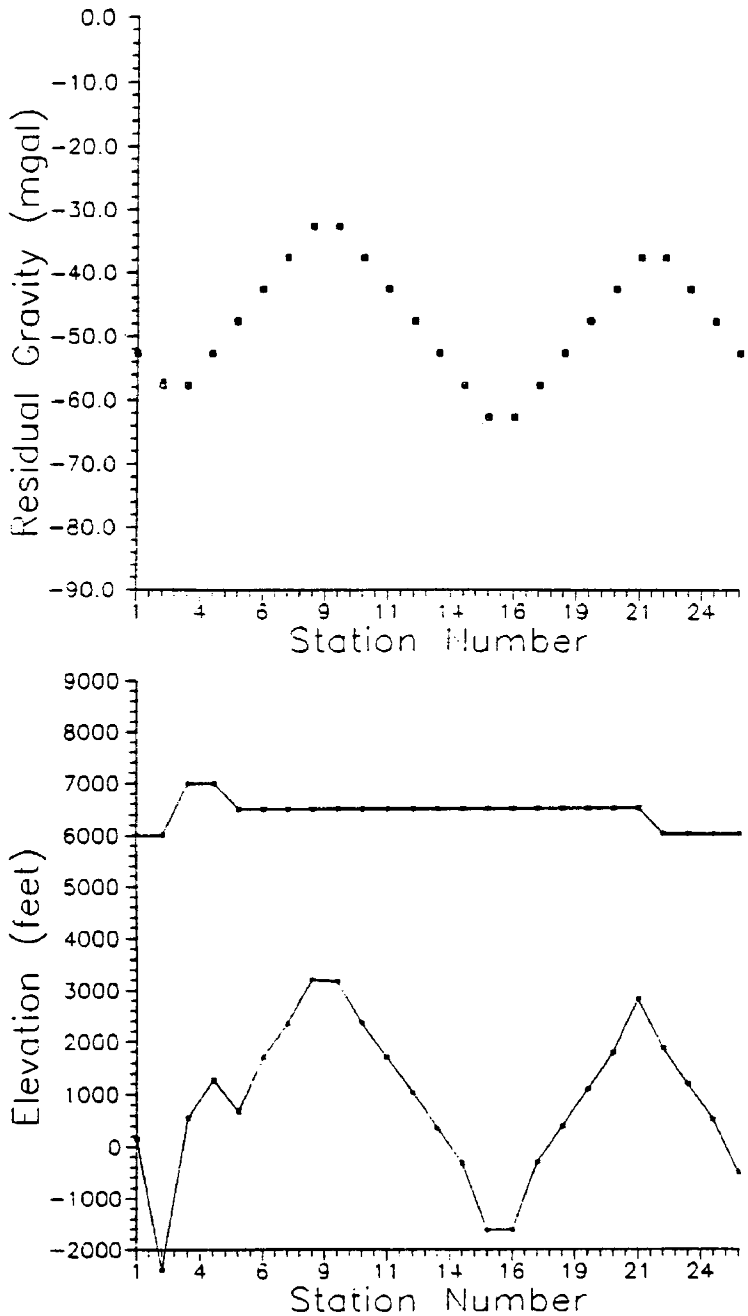


Fig 6.10 Computer inverted profile
Derco-Hunt Profile
❑ Observed Gravity * Calculated Gravity

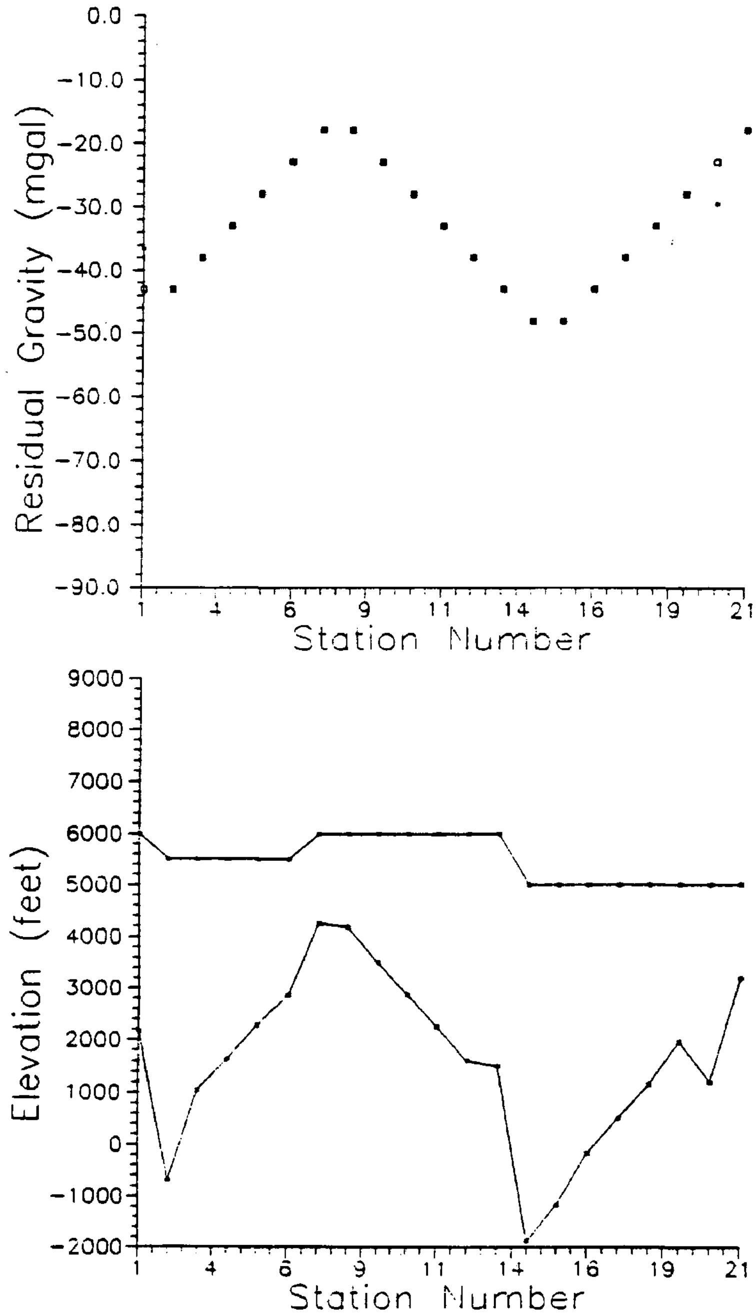


Fig 6.11 Computer inverted profile
Apache-Federal Profile
□ Observed Gravity * Calculated Gravity

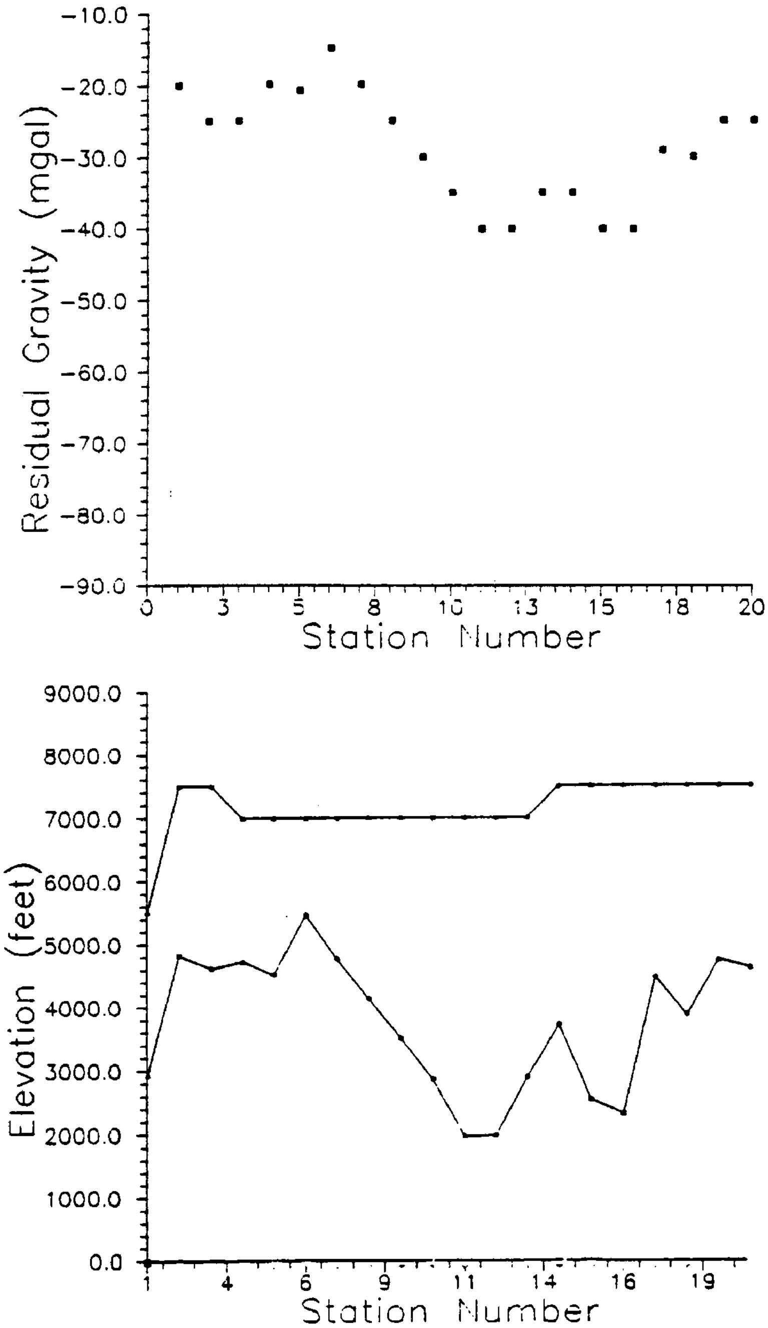
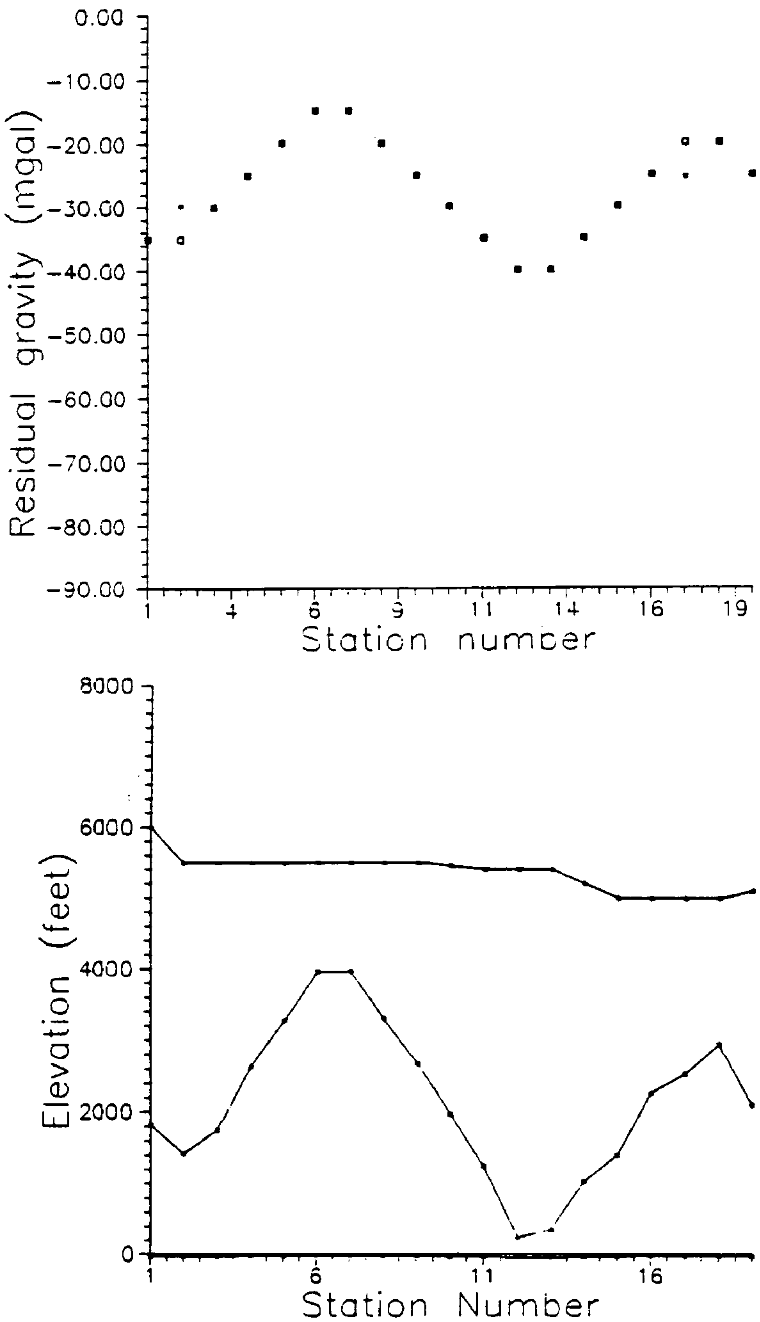


Fig 6.12 Computer inverted profile
Celsius-Conoco Profile
□ Observed Gravity * Calculated Gravity



6.13 Computer inverted profile
Warm Springs-Supron Profile
□ Observed Gravity * Calculated Gravity

SECTION 7

Compilation of a Conductance map of Nevada

The compilation of a conductance map of the investigated area, which covers the State of Nevada, has been the object of the present work. As described in Section Two, a good knowledge of the surface conductance in this area of highly conductive basin-filled sediments is mandatory in order to correct magnetotelluric sounding curves from the screening effect exercised by such a conductive layer.

In order to obtain the conductance map, the author used the theoretical relationship between the residual gravity effect of each valley and the conductance parameter, as derived in Section Five.

In order to check the theoretical validity of the relationship previously described, the author first calculated a residual gravity map of basins in Nevada from values of residual gravity at each well location. Those values were obtained subtracting the gravity, obtained from the map in figure 6.8, at each well location from the gravity values of points located along the edges of each basin containing a well.

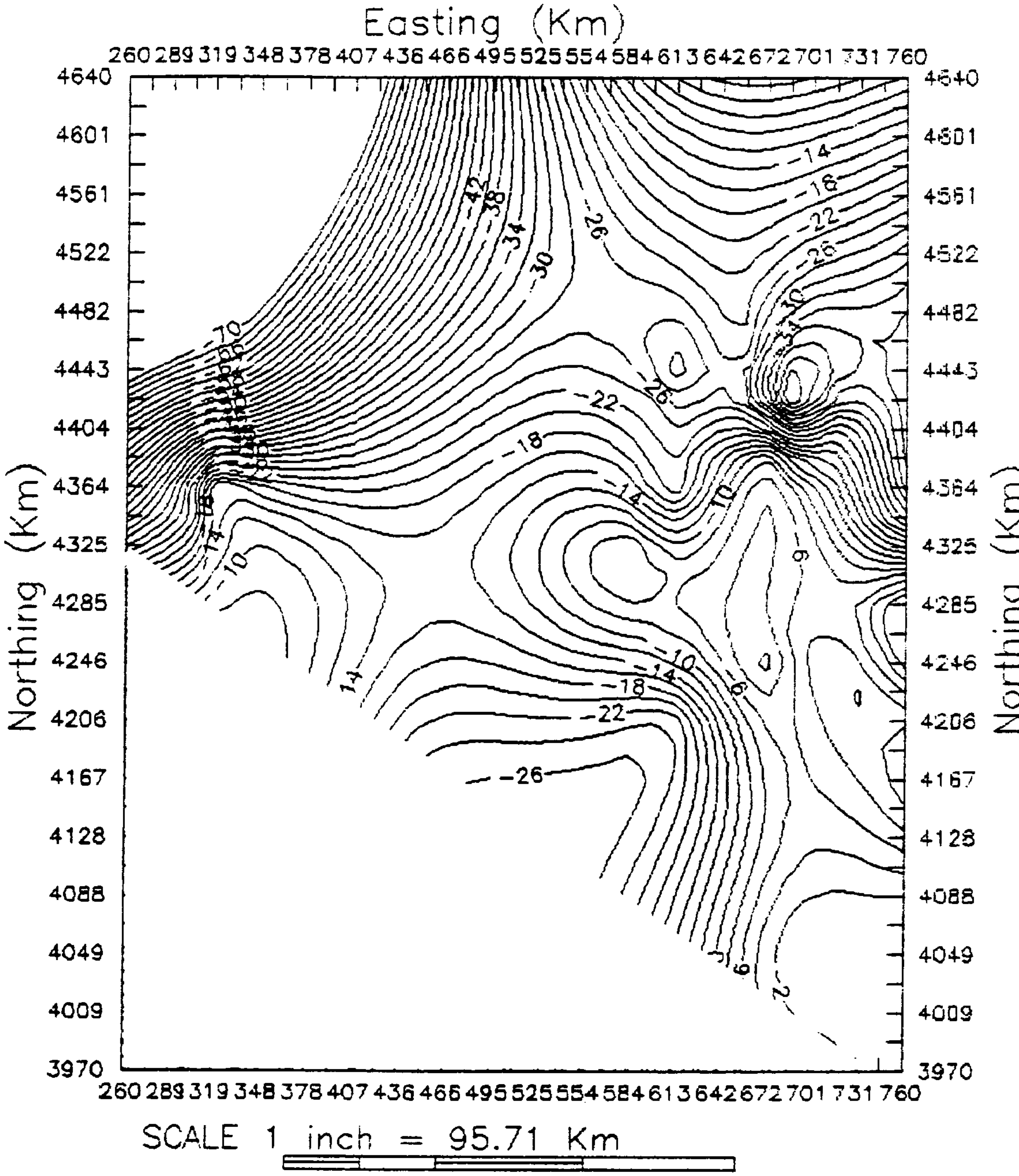
The obtained residual gravity values namely represent the gravitational attraction of those sections of the basins stretching from their edges to each well location inside the same basin.

The obtained residual gravity map is pictured in figure 7.1. From this last map, it is possible to directly derive conductance values using the expression (5.8), as described in Section Five.

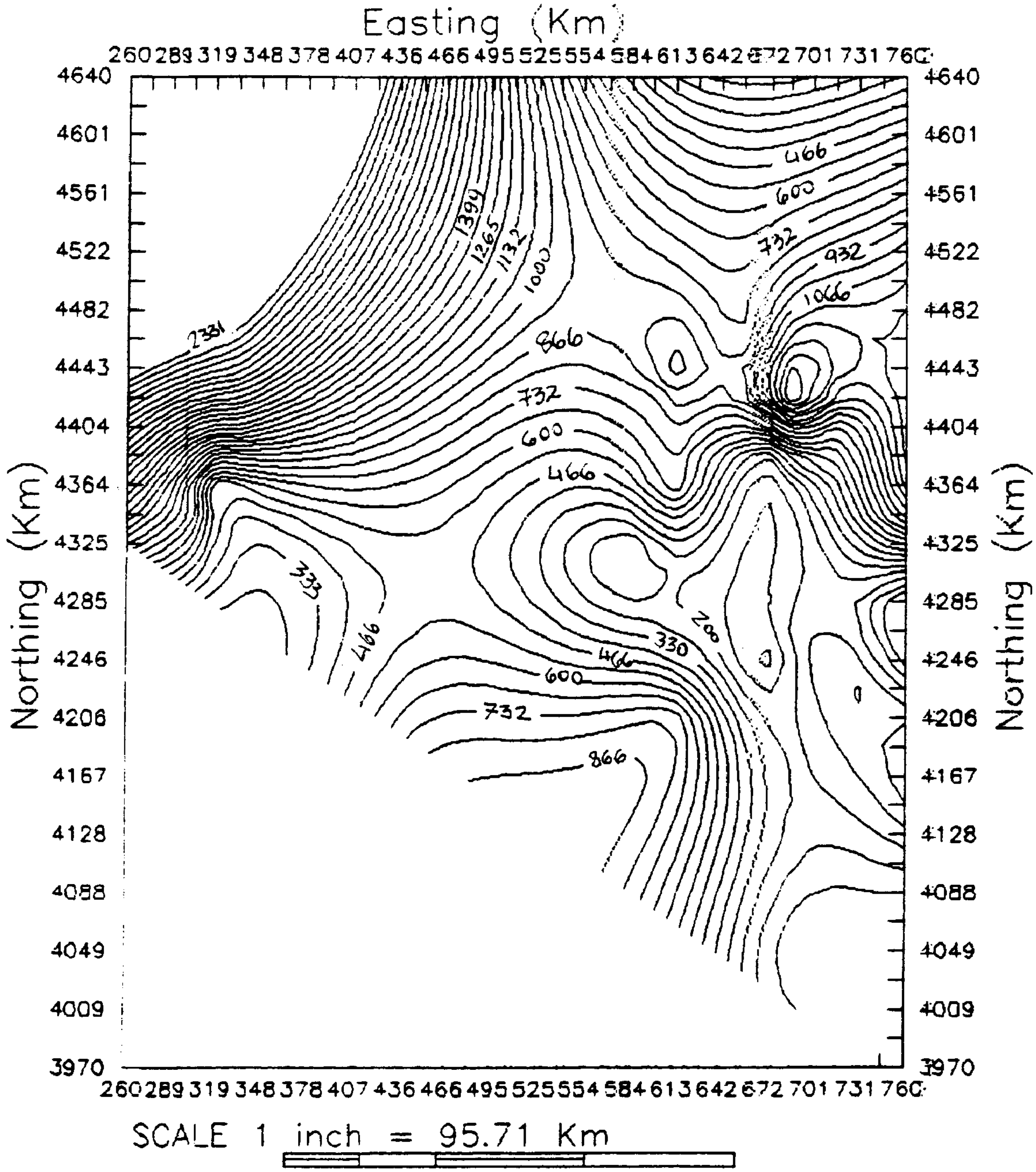
A map of surface conductance in figure 7.2 was so obtained from residual gravity values calculated at each well location.

Furthermore, conductance values derived at all well locations were used to draw a contour map of surface conductance as derived by resistivity well log data. The analysis of this map, in figure 7.3, show a very good similarity with the conductance map in figure 7.2, derived from gravity data at each well location. The very good match between the two maps of conductance, one derived from gravity data through expression 5.8, the other obtained from conductance values calculated from well log data, proves that the theoretical relationship, relating residual gravity to conductance, is correct.

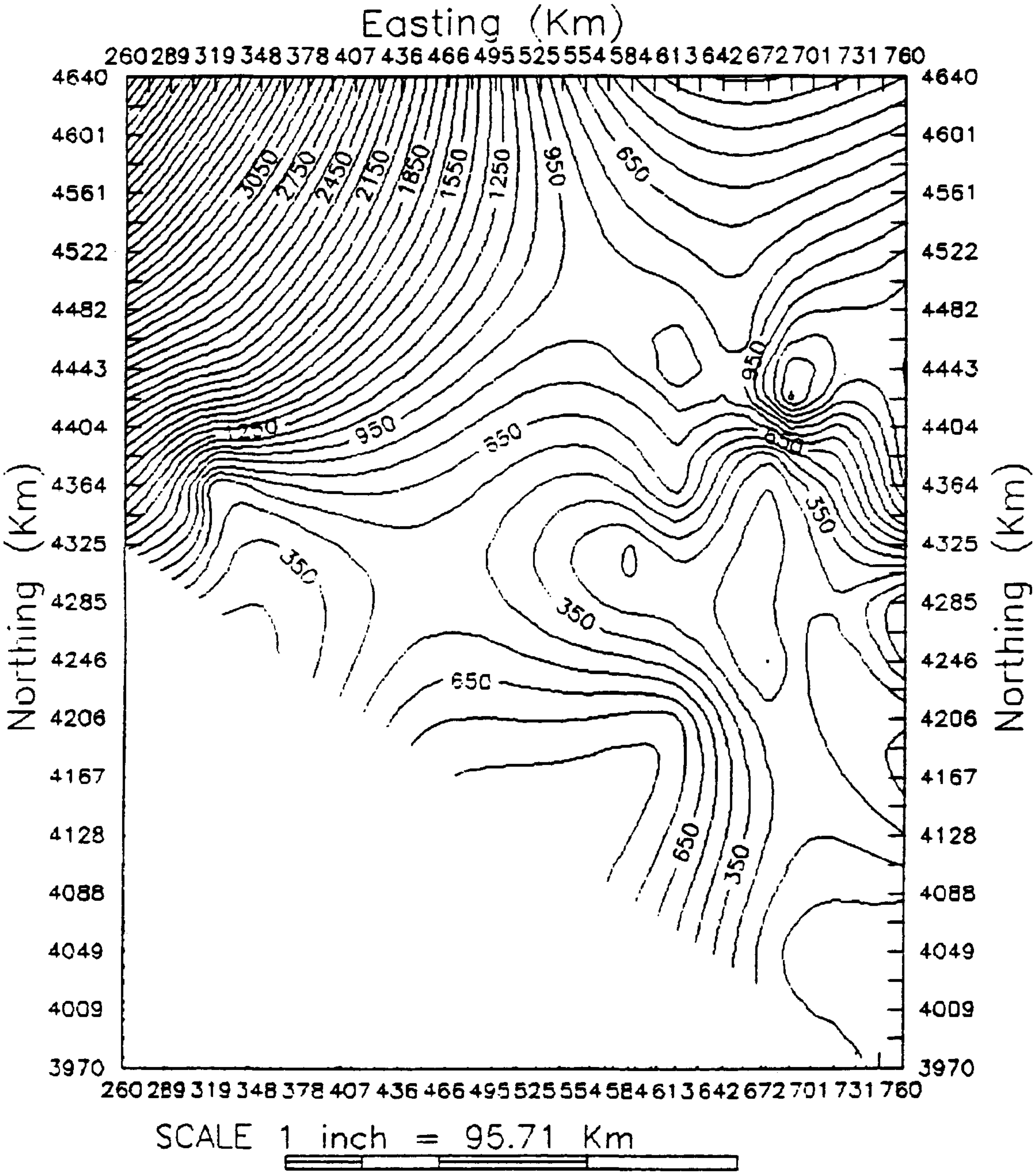
In order to have a more detailed surface conductance map of Nevada with respect to those obtained from gravity and conductance values known only at each well location, first, a Bouguer map of Nevada showing only the gravity effect related to the basins has been obtained from a complete Bouguer map of the area, subtracting the effect due to mountains and general topographic relief. The second step has consisted in calculating the residual gravity effect of the basins from the regional gravity map. This has been accomplished subtracting the gravity, obtained from the map, at 150 grid points regularly spaced inside the basins, from the gravity values of a series of chosen, also regularly spaced, points located all along the edges of each basin.



7.1 Residual gravity map of basins in Nevada derived from values at selected well sites (Contour units mgal)



7.2 Conductance map of Nevada derived from gravity data known at selected well sites (Contour units siemens)



7.3 Conductance map of Nevada derived from values at selected well sites (Contour units siemens)

Once obtained, those gravity values namely representing the residual gravity effect of the basins, the author made a contour map of them as pictured in figure 7.4. This map represents the residual gravity associated with the basins of Nevada. The values have been found to range form -2 to -36 milligals.

Using expression (5.8), previously derived and explained, the author calculated the conductance values from the residual gravity map of figure 7.1 simply by multiplying the values of residual gravity contours, as derived from the map, by the coefficient $\frac{1}{aP_{median}}$ previously calculated.

Therefore the numerical expressions that has been used which takes into account the derived relationship between conductance (S) and residual gravity (ΔG) is:

$$S = 33.304934\Delta G \tag{7.1}$$

Multiplication of residual gravity contours, as in figure 7.1, by the coefficient $\frac{1}{aP_{median}}$, yields conductance values directly. Such conductance contour values were plotted in figure 7.5 and are representatives of the surface conductance of all the basins of Nevada, as derived through equation (5.8).

The analysis of such a map, pictured in figure 7.5, shows high values of conductance, due to surface sediments, in accordance with recent studies of the surface conductance of Western United States (Keller, 1989). The range of values obtained for Nevada spans from 37 to 1,300 Siemens. These values are considerably higher than those found in the surrounding areas, but well correlate with the order of magnitude of conductance measured in Southern California, at the border with Nevada. Nonetheless, the author, considering the

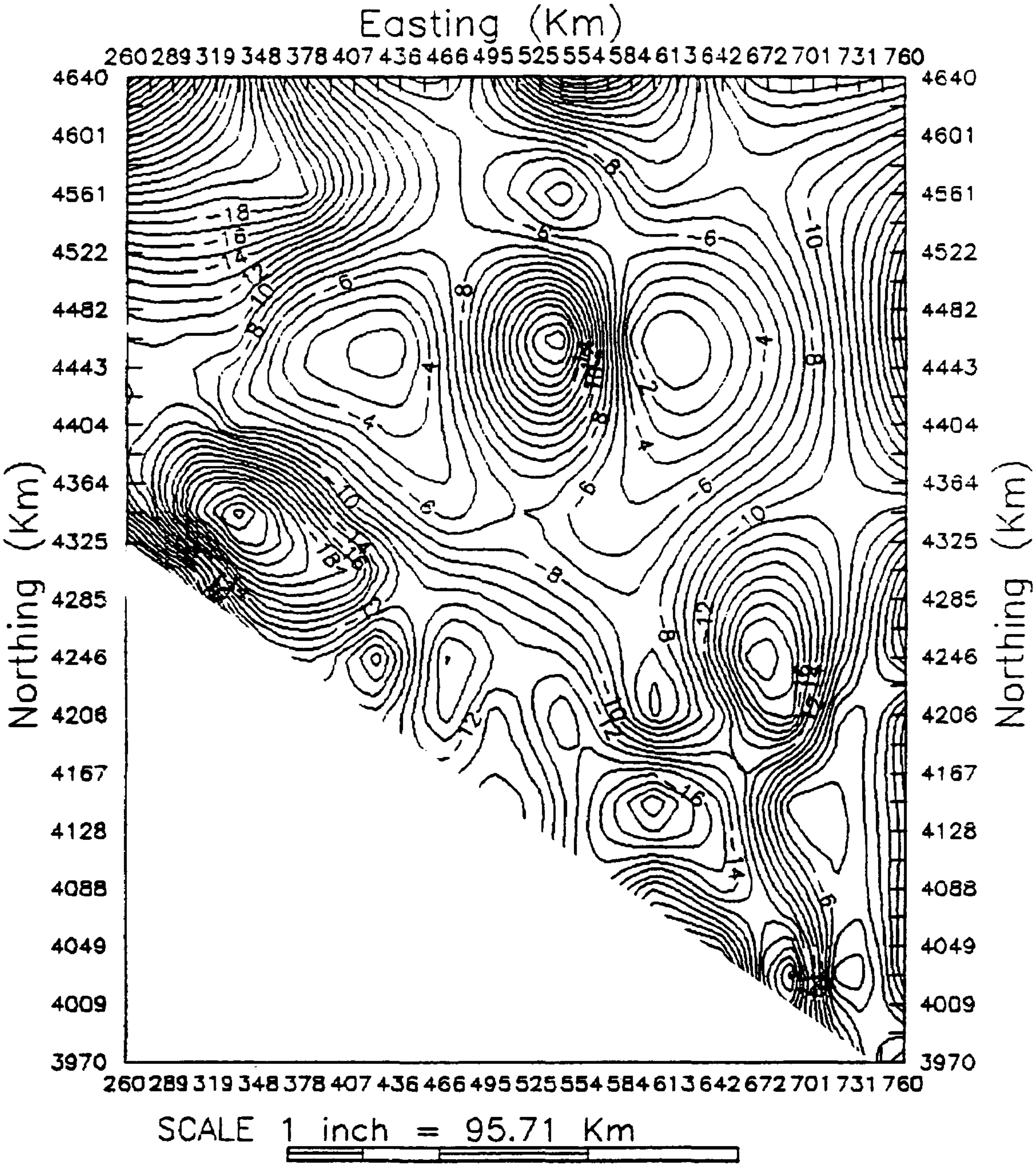


Fig 7.4 Residual gravity map of basins in Nevada (Contour units mgal)

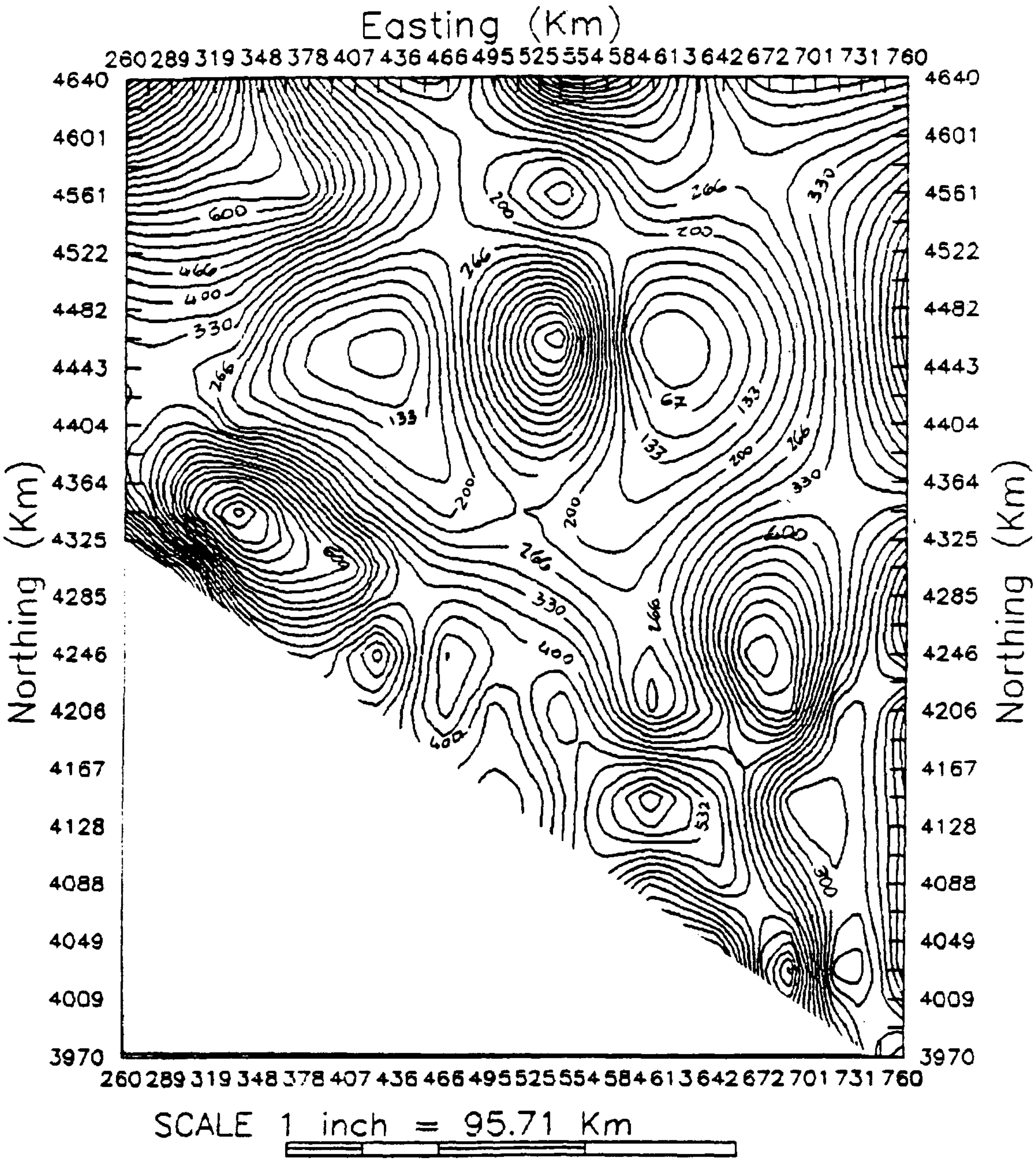


Fig 7.5 Conductance map of Nevada derived from gravity data (Contour units siemens)

values obtained from the previously mentioned studies, believes that the values of surface conductance in Nevada are considerably higher than those found in contiguous areas.

Therefore the screening effect on electrical soundings, due to such a conductive layer, must be remarkably higher in this area, posing a significant problem to the use of electrical probing methods at great depths.

Nevertheless, as described in Section Two, a good knowledge of the conductance values of surface rocks and sediments is mandatory in order to correct the magnetotelluric curves obtained in this area.

The results of the present study, summarized in terms of a conductance map of Nevada, may be used in order to perform the correction on magnetotelluric curves acquired in the area.

The work, also wishes to testify the good applicability of the correlation between gravity and conductance data in order to estimate surface conductance values required to correct magnetotelluric survey curves performed in other areas of the world where such screening effect tends to be present.

SECTION 8

Conclusions

From analysis presented in this thesis it is apparent that it is possible to derive conductance values from gravity data covering the State of Nevada. The theoretical relationship derived allows us to calculate conductance values directly from residual gravity data under the assumption of approximating the gravitational attraction of a valley to the attraction for an infinite slab. Furthermore, in order to be able to use the theoretical relationship, values of porosity, matrix density and median resistivity must be known.

A surface conductance map of Nevada has been produced from gravity data, calculated at each well location, and was found in good agreement with the conductance map obtained from contoured conductance values at selected well locations. Furthermore, a more detailed surface conductance map has been obtained from gravity data calculated on a grid of 150 regularly spaced points.

The high values of conductance seriously distort magnetotelluric curves surveyed in the area, and a good estimate of their magnitude and distribution would help to correct the curves for this screening effect.

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Appendix 1

Tabulated data from computer gravity inversion and data for resistivity logs.

```
WHITER AMOCO PROFILE
DX,ITOTL,NUMCP,MAXIT,ERR : 7568. , 24 ,  2 , 15 , .200
IFLAG1,IFLAG2,IFLAG3,IFLAG4,IFLAG5 :-1 ,-1 , 4 , 2 ,-1
BASEMENT DENSITY IN GM/CC=2.67
STA  PRISM    FIRST    MEASURD
    NUM  DENS     GUESS    GRAVITY
         CONTRST  DEPTH
     1     -.67   2866.   -195.00       2     -.67   3000.   -195.00
     3     -.67   3000.   -200.00       4     -.67   3000.   -205.00
     5     -.67   3000.   -210.00       6     -.67   3000.   -215.00
     7     -.67   3000.   -215.00       8     -.67   3000.   -210.00
     9     -.67   3000.   -205.00      10     -.67   3000.   -205.00
    11     -.67   3000.   -205.00      12     -.67   3000.   -205.00
    13     -.67   3000.   -210.00      14     -.67   3000.   -215.00
    15     -.67   3000.   -220.00      16     -.67   3000.   -225.00
    17     -.67   3000.   -230.00      18     -.67   3000.   -230.00
    19     -.67   3000.   -225.00      20     -.67   3000.   -220.00
    21     -.67   3000.   -215.00      22     -.67   3000.   -210.00
    23     -.67   3422.   -205.00      24     -.67   3000.   -205.00
 STATION NUMBER AND DEPTH OF CONSTRAINED POINTS:
    1   2866.
   23   3422.
REGIONAL IN FORM Y=A0+A1*X+A2*(X*X)
Y IS CORRECTION IN MGALS
X IS STATION NUMBER
FOR A LINEAR REGIONAL, "A2" IS ZERO AND
A0 IS THE Y-INTERCEPT AND
A1 IS THE SLOPE. THE ORIGIN IS ONE STATION
POSITION OFF THE END FROM  THE FIRST STATION.
INPUT REGIONAL: A0=    .000     A1=   .000 A2=   .000
 NUMIT= 1    SGRSQ=  5593.232
 NUMIT= 2    SGRSQ=   296.198
 NUMIT= 3    SGRSQ=    38.923
 NUMIT= 4    SGRSQ=     9.081
 NUMIT= 5    SGRSQ=     3.601
 NUMIT= 6    SGRSQ=     2.015
 NUMIT= 7    SGRSQ=     1.351
 NUMIT= 8    SGRSQ=     1.004
 NUMIT= 9    SGRSQ=      .798
  JOB TERMINATED.
 ERROR IS WITHIN TOLERANCE.
 NUMIT= 9   SGRSQ=      .80  SERRSQ=      .96
FINAL REGIONAL: A0=-170.249     A1=   .000 A2=   .000
2815.,  2529.,  3363.,  4027.,  4655.,  6563.,  5401.,  4578.,  3564.,  3912.,
3895.,  3521.,  4496.,  5166.,  5853.,  6572.,  8264.,  8266.,  6577.,  5861.,
5173.,  4555.,  3473.,  3977.,
1,  2866., 23,  3422.,
```

DATA TABULATION,

STA NUM	SURFACE ELEV	MEASURD GRAVITY MINUS REGIONAL	COMPUTED GRAVITY	MEAS. GRAV. MINUS CALC. GRAV.	BASEMNT ELEV.	DEPTH TO BASEMT
1	5500.	-24.75	-25.19	.43	2634.	2815.
2	5500.	-24.75	-24.74	-.01	2971.	2529.
3	5500.	-29.75	-29.73	-.02	2137.	3363.
4	5500.	-34.75	-34.72	-.03	1473.	4027.
5	5500.	-39.75	-39.94	.19	845.	4655.
6	5500.	-44.75	-44.38	-.37	-1063.	6563.
7	6000.	-44.75	-44.90	.15	599.	5401.
8	6000.	-39.75	-39.73	-.02	1422.	4578.
9	6000.	-34.75	-34.78	.03	2436.	3564.
10	6000.	-34.75	-34.72	-.03	2088.	3912.
11	6000.	-34.75	-34.72	-.03	2105.	3895.
12	6000.	-34.75	-34.78	.03	2479.	3521.
13	6000.	-39.75	-39.71	-.04	1504.	4496.
14	6000.	-44.75	-44.74	-.02	834.	5166.
15	6000.	-49.75	-49.74	-.01	147.	5853.
16	6000.	-54.75	-54.98	.23	-572.	6572.
17	6000.	-59.75	-59.51	-.24	-2264.	8264.
18	6000.	-59.75	-59.51	-.24	-2266.	8266.
19	6000.	-54.75	-54.98	.22	-577.	6577.
20	6000.	-49.75	-49.74	-.01	139.	5861.
21	6000.	-44.75	-44.74	-.01	827.	5173.
22	6000.	-39.75	-39.72	-.03	1445.	4555.
23	6000.	-34.75	-34.32	-.43	2578.	3473.
24	6000.	-34.75	-34.74	-.01	2023.	3977.

WHITER AMOCO PROFILE

```
 24
 -24.75 -24.75 -29.75 -34.75 -39.75 -44.75 -44.75 -39.75 -34.75 -34.75
 -34.75 -34.75 -39.75 -44.75 -49.75 -54.75 -59.75 -59.75 -54.75 -49.75
 -44.75 -39.75 -34.75 -34.75
 -25.19 -24.74 -29.73 -34.72 -39.94 -44.38 -44.90 -39.73 -34.78 -34.72
 -34.72 -34.78 -39.71 -44.74 -49.74 -54.98 -59.51 -59.51 -54.98 -49.74
 -44.74 -39.72 -34.32 -34.74
  5500.  5500.  5500.  5500.  5500.  5500.  6000.  6000.  6000.  6000.
  6000.  6000.  6000.  6000.  6000.  6000.  6000.  6000.  6000.  6000.
  6000.  6000.  6000.  6000.
  2634.  2971.  2137.  1473.   845. -1063.   599.  1422.  2436.  2088.
  2105.  2479.  1504.   834.   147.  -572. -2264. -2266.  -577.   139.
   827.  1445.  2578.  2023.
```

```
DERCO HUNT PROFILE
DX,ITOTL,NUMCP,MAXIT,ERR :10306. , 25 ,  2 , 15 , .200
IFLAG1,IFLAG2,IFLAG3,IFLAG4,IFLAG5 :-1 ,-1 , 4 , 2 ,-1
BASEMENT DENSITY IN GM/CC=2.67
STA  PRISM    FIRST    MEASURD
   NUM  DENS     GUESS    GRAVITY
        CONTRST  DEPTH
    1     -.67   3400.   -210.00       2     -.67   3400.   -215.00
    3     -.67   3400.   -215.00       4     -.67   3400.   -210.00
    5     -.67   3400.   -205.00       6     -.67   3400.   -200.00
    7     -.67   3400.   -195.00       8     -.67   3295.   -190.00
    9     -.67   3400.   -190.00      10     -.67   3400.   -195.00
   11     -.67   3400.   -200.00      12     -.67   3400.   -205.00
   13     -.67   3400.   -210.00      14     -.67   3400.   -215.00
   15     -.67   3400.   -220.00      16     -.67   3400.   -220.00
   17     -.67   3400.   -215.00      18     -.67   3400.   -210.00
   19     -.67   3400.   -205.00      20     -.67   3400.   -200.00
   21     -.67   3678.   -195.00      22     -.67   3400.   -195.00
   23     -.67   3400.   -200.00      24     -.67   3400.   -205.00
   25     -.67   3400.   -210.00
 STATION NUMBER AND DEPTH OF CONSTRAINED POINTS:
    8   3295.
   21   3678.
REGIONAL IN FORM Y=A0+A1*X+A2*(X*X)
Y IS CORRECTION IN MGALS
X IS STATION NUMBER
FOR A LINEAR REGIONAL, "A2" IS ZERO AND
A0 IS THE Y-INTERCEPT AND
A1 IS THE SLOPE. THE ORIGIN IS ONE STATION
POSITION OFF THE END FROM  THE FIRST STATION.
INPUT REGIONAL: A0=    .000     A1=   .000 A2=   .000
 NUMIT= 1    SGRSQ=  6453.950
 NUMIT= 2    SGRSQ=   354.615
 NUMIT= 3    SGRSQ=    44.499
 NUMIT= 4    SGRSQ=    10.392
 NUMIT= 5    SGRSQ=     4.089
 NUMIT= 6    SGRSQ=     2.114
 NUMIT= 7    SGRSQ=     1.231
 NUMIT= 8    SGRSQ=      .761
  JOB TERMINATED.
 ERROR IS WITHIN TOLERANCE.
 NUMIT= 8   SGRSQ=      .76  SERRSQ=     1.00
FINAL REGIONAL: A0=-157.341     A1=   .000 A2=   .000
5843., 8393., 6445., 5729., 5822., 4799., 4150., 3313., 3324., 4135.,
4798., 5462., 6134., 6816., 8125., 8119., 6798., 6101., 5405., 4711.,
3660., 4131., 4812., 5482., 6498.,
8, 3295., 21, 3678.,
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DATA TABULATION,

STA NUM	SURFACE ELEV	MEASURD GRAVITY MINUS REGIONAL	COMPUTED GRAVITY	MEAS. GRAV. MINUS CALC. GRAV.	BASEMNT ELEV.	DEPTH TO BASEMT
1	6000.	-52.66	-52.84	.19	157.	5843.
2	6000.	-57.66	-56.94	-.72	-2393.	8393.
3	7000.	-57.66	-57.91	.25	555.	6445.
4	7000.	-52.66	-52.72	.06	1271.	5729.
5	6500.	-47.66	-47.52	-.14	678.	5822.
6	6500.	-42.66	-42.68	.02	1701.	4799.
7	6500.	-37.66	-37.62	-.04	2350.	4150.
8	6500.	-32.66	-32.51	-.15	3205.	3313.
9	6500.	-32.66	-32.64	-.02	3176.	3324.
10	6500.	-37.66	-37.63	-.03	2365.	4135.
11	6500.	-42.66	-42.64	-.02	1702.	4798.
12	6500.	-47.66	-47.63	-.03	1038.	5462.
13	6500.	-52.66	-52.63	-.03	366.	6134.
14	6500.	-57.66	-57.76	.11	-316.	6816.
15	6500.	-62.66	-62.51	-.15	-1625.	8125.
16	6500.	-62.66	-62.51	-.15	-1619.	8119.
17	6500.	-57.66	-57.77	.11	-298.	6798.
18	6500.	-52.66	-52.63	-.03	399.	6101.
19	6500.	-47.66	-47.64	-.02	1095.	5405.
20	6500.	-42.66	-42.62	-.04	1789.	4711.
21	6500.	-37.66	-37.81	.15	2822.	3660.
22	6000.	-37.66	-37.63	-.03	1869.	4131.
23	6000.	-42.66	-42.63	-.03	1188.	4812.
24	6000.	-47.66	-47.69	.03	518.	5482.
25	6000.	-52.66	-52.61	-.05	-498.	6498.

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DERCO HUNT PROFILE
 25
 -52.66 -57.66 -57.66 -52.66 -47.66 -42.66 -37.66 -32.66 -32.66 -37.66
 -42.66 -47.66 -52.66 -57.66 -62.66 -62.66 -57.66 -52.66 -47.66 -42.66
 -37.66 -37.66 -42.66 -47.66 -52.66
 -52.84 -56.94 -57.91 -52.72 -47.52 -42.68 -37.62 -32.51 -32.64 -37.63
 -42.64 -47.63 -52.63 -57.76 -62.51 -62.51 -57.77 -52.63 -47.64 -42.62
 -37.81 -37.63 -42.63 -47.69 -52.61
  6000.  6000.  7000.  7000.  6500.  6500.  6500.  6500.  6500.  6500.
  6500.  6500.  6500.  6500.  6500.  6500.  6500.  6500.  6500.  6500.
  6500.  6000.  6000.  6000.  6000.
   157. -2393.   555.  1271.   678.  1701.  2350.  3205.  3176.  2365.
  1702.  1038.   366.  -316. -1625. -1619.  -298.   399.  1095.  1789.
  2822.  1869.  1188.   518.  -498.
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APACHE FEDERAL PROFILE
DX,ITOTL,NUMCP,MAXIT,ERR :10561. , 21 , 2 , 15 , .200
IFLAG1,IFLAG2,IFLAG3,IFLAG4,IFLAG5 :-1 ,-1 , 4 , 2 ,-1
BASEMENT DENSITY IN GM/CC=2.67
STA  PRISM    FIRST    MEASURD
   NUM  DENS     GUESS    GRAVITY
        CONTRST  DEPTH
    1     -.67   3825.   -225.00       2      -.67   3900.   -225.00
    3     -.67   3800.   -220.00       4      -.67   3800.   -215.00
    5     -.67   3800.   -210.00       6      -.67   3800.   -205.00
    7     -.67   3800.   -200.00       8      -.67   3800.   -200.00
    9     -.67   3800.   -205.00      10      -.67   3800.   -210.00
   11     -.67   3800.   -215.00      12      -.67   3800.   -220.00
   13     -.67   3800.   -225.00      14      -.67   3800.   -230.00
   15     -.67   3800.   -230.00      16      -.67   3800.   -225.00
   17     -.67   3800.   -220.00      18      -.67   3800.   -215.00
   19     -.67   3800.   -210.00      20      -.67   3805.   -205.00
   21     -.67   3900.   -200.00
 STATION NUMBER AND DEPTH OF CONSTRAINED POINTS:
    1   3828.
   20   3805.
REGIONAL IN FORM Y=A0+A1*X+A2*(X*X)
Y IS CORRECTION IN MGALS
X IS STATION NUMBER
FOR A LINEAR REGIONAL, "A2" IS ZERO AND
A0 IS THE Y-INTERCEPT AND
A1 IS THE SLOPE. THE ORIGIN IS ONE STATION
POSITION OFF THE END FROM  THE FIRST STATION.
INPUT REGIONAL: A0=    .000     A1=   .000 A2=   .000
 NUMIT= 1    SGRSQ=  2049.373
 NUMIT= 2    SGRSQ=   122.126
 NUMIT= 3    SGRSQ=   103.652
 NUMIT= 4    SGRSQ=    92.908
 NUMIT= 5    SGRSQ=    89.054
 NUMIT= 6    SGRSQ=    87.194
 NUMIT= 7    SGRSQ=    86.180
 NUMIT= 8    SGRSQ=    85.590
 NUMIT= 9    SGRSQ=    85.227
 NUMIT=10    SGRSQ=    84.999
 NUMIT=11    SGRSQ=    84.851
 NUMIT=12    SGRSQ=    84.755
 NUMIT=13    SGRSQ=    84.691
 NUMIT=14    SGRSQ=    84.648
 NUMIT=15    SGRSQ=    84.621
  JOB TERMINATED,
 NUMIT(15 ) EQUALLED MAXIT(15 )
 BEFORE ERROR TOLERANCE WAS REACHED,
 SGRSQ=    84.62      SERRSQ=      .84
FINAL REGIONAL: A0=-181.979     A1=   .000 A2=   .000
4588., 6192., 4458., 3872., 3215., 2638., 1747., 1819., 2505., 3134.,
3753., 4402., 4508., 6884., 6162., 5164., 4500., 3847., 3041., 3045.,
1807.,
1, 3828., 20, 3805.,
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DATA TABULATION,

STA NUM	SURFACE ELEV	MEASURD GRAVITY MINUS REGIONAL	COMPUTED GRAVITY	MINUS CALC. GRAV.		MEAS. GRAV. BASEMT	BASEMNT ELEV.	DEPTH TO
1	6000.	-43.02	-36.52	-6.50	2172.	4588.		
2	5500.	-43.02	-43.01	-.01	-692.	6192.		
3	5500.	-38.02	-38.03	.01	1042.	4458.		
4	5500.	-33.02	-33.02	.00	1628.	3872.		
5	5500.	-28.02	-28.02	.00	2285.	3215.		
6	5500.	-23.02	-23.02	.00	2862.	2638.		
7	6000.	-18.02	-18.02	.00	4253.	1747.		
8	6000.	-18.02	-18.02	.00	4181.	1819.		
9	6000.	-23.02	-23.02	.00	3495.	2505.		
10	6000.	-28.02	-28.02	.00	2866.	3134.		
11	6000.	-33.02	-33.02	.00	2247.	3753.		
12	6000.	-38.02	-38.02	-.01	1598.	4402.		
13	6000.	-43.02	-43.03	.01	1492.	4508.		
14	5000.	-48.02	-48.00	-.03	-1884.	6884.		
15	5000.	-48.02	-48.03	.01	-1162.	6162.		
16	5000.	-43.02	-43.02	-.01	-164.	5164.		
17	5000.	-38.02	-38.02	.00	500.	4500.		
18	5000.	-33.02	-33.02	.00	1153.	3847.		
19	5000.	-28.02	-28.02	.00	1959.	3041.		
20	5000.	-23.02	-29.53	6.50	1195.	3045.		
21	5000.	-18.02	-18.02	.00	3193.	1807.		

APACHE FEDERAL PROFILE

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-43.02 -43.02 -38.02 -33.02 -28.02 -23.02 -18.02 -18.02 -23.02 -28.02
-33.02 -38.02 -43.02 -48.02 -48.02 -43.02 -38.02 -33.02 -28.02 -23.02
-18.02
-36.52 -43.01 -38.03 -33.02 -28.02 -23.02 -18.02 -18.02 -23.02 -28.02
-33.02 -38.02 -43.03 -48.00 -48.03 -43.02 -38.02 -33.02 -28.02 -29.53
-18.02
6000. 5500. 5500. 5500. 5500. 5500. 6000. 6000. 6000. 6000.
6000. 6000. 6000. 5000. 5000. 5000. 5000. 5000. 5000. 5000.
5000.
2172. -692. 1042. 1628. 2285. 2862. 4253. 4181. 3495. 2866.
2247. 1598. 1492. -1884. -1162. -164. 500. 1153. 1959. 1195.
3193.

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CELSIUS CONOCO PROFILE
DX,ITOTL,NUMCP,MAXIT,ERR :12460. , 20 ,  2 , 15 , .200
IFLAG1,IFLAG2,IFLAG3,IFLAG4,IFLAG5 :-1 ,-1 , 4 , 2 ,-1
BASEMENT DENSITY IN GM/CC=2.67
STA  PRISM    FIRST    MEASURD
  NUM  DENS     GUESS    GRAVITY
       CONTRST  DEPTH
   1     -.67   2700.   -210.00       2     -.67  2700.   -215.00
   3     -.67   2700.   -215.00       4     -.67  2700.   -210.00
   5     -.67   2468.   -205.00       6     -.67  2700.   -205.00
   7     -.67   2700.   -210.00       8     -.67  2700.   -215.00
   9     -.67   2700.   -220.00      10     -.67  2700.   -225.00
  11     -.67   2700.   -230.00      12     -.67  2700.   -230.00
  13     -.67   2700.   -225.00      14     -.67  2700.   -225.00
  15     -.67   2700.   -230.00      16     -.67  2700.   -230.00
  17     -.67   3012.   -225.00      19     -.67  2700.   -220.00
  19     -.67   2700.   -215.00      20     -.67  2700.   -215.00
 STATION NUMBER AND DEPTH OF CONSTRAINED POINTS:
   5   2468.
  17   3012.
REGIONAL IN FORM Y=A0+A1*X+A2*(X*X)
Y IS CORRECTION IN MGALS
X IS STATION NUMBER
FOR A LINEAR REGIONAL, "A2" IS ZERO AND
A0 IS THE Y-INTERCEPT AND
A1 IS THE SLOPE. THE ORIGIN IS ONE STATION
POSITION OFF THE END FROM  THE FIRST STATION.
INPUT REGIONAL: A0=    .000     A1=   .000 A2=   .000
 NUMIT= 1    SGRSQ=  1377.316
 NUMIT= 2    SGRSQ=   127.876
 NUMIT= 3    SGRSQ=    80.492
 NUMIT= 4    SGRSQ=    72.553
 NUMIT= 5    SGRSQ=    70.329
 NUMIT= 6    SGRSQ=    69.551
 NUMIT= 7    SGRSQ=    69.236
 NUMIT= 8    SGRSQ=    69.095
 NUMIT= 9    SGRSQ=    69.028
 NUMIT=10    SGRSQ=    68.996
 NUMIT=11    SGRSQ=    68.980
 NUMIT=12    SGRSQ=    68.973
 NUMIT=13    SGRSQ=    68.967
 NUMIT=14    SGRSQ=    68.965
 NUMIT=15    SGRSQ=    68.964
  JOB TERMINATED,
 NUMIT(15 ) EQUALLED MAXIT(15 )
 BEFORE ERROR TOLERANCE WAS REACHED,
 SGRSQ=    68.96      SERRSQ=      .80
FINAL REGIONAL: A0=-189.963     A1=   .000 A2=   .000
2581., 2672., 2869., 2262., 1782., 1523., 2228., 2856., 3490., 4132.,
5022., 5010., 4095., 3766., 4947., 5173., 3698., 3616., 2751., 2875.,
5, 2468., 17, 3012.,
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DATA TABULATION,

STA NUM	SURFACE ELEV	MEASURD GRAVITY MINUS REGIONAL	COMPUTED GRAVITY	MINUS CALC. GRAV.	Elev	MEAS. GRAV. BASEMT	BASEMNT ELEV.	DEPTH TO
1	5500.	-20.04	-20.04	.00	2919.	2581.		
2	7500.	-25.04	-25.04	.00	4828.	2672.		
3	7500.	-25.04	-25.04	.00	4631.	2869.		
4	7000.	-20.04	-20.04	.00	4738.	2262.		
5	7000.	-15.04	-20.91	5.87	4532.	1782.		
6	7000.	-15.04	-15.04	.00	5477.	1523.		
7	7000.	-20.04	-20.04	.00	4772.	2228.		
8	7000.	-25.04	-25.04	.00	4144.	2856.		
9	7000.	-30.04	-30.04	.00	3510.	3490.		
10	7000.	-35.04	-35.04	.00	2868.	4132.		
11	7000.	-40.04	-40.04	.00	1978.	5022.		
12	7000.	-40.04	-40.04	.00	1990.	5010.		
13	7000.	-35.04	-35.04	.00	2905.	4095.		
14	7500.	-35.04	-35.04	.00	3734.	3766.		
15	7500.	-40.04	-40.04	.00	2553.	4947.		
16	7500.	-40.04	-40.04	.00	2327.	5173.		
17	7500.	-35.04	-29.16	-5.87	4488.	3698.		
18	7500.	-30.04	-30.04	.00	3884.	3616.		
19	7500.	-25.04	-25.04	.00	4749.	2751.		
20	7500.	-25.04	-25.04	.00	4625.	2875.		

CELSIUS CONOCO PROFILE

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-20.04	-25.04	-25.04	-20.04	-15.04	-15.04	-20.04	-25.04	-30.04	-35.04
-40.04	-40.04	-35.04	-35.04	-40.04	-40.04	-35.04	-30.04	-25.04	-25.04
-20.04	-25.04	-25.04	-20.04	-20.91	-15.04	-20.04	-25.04	-30.04	-35.04
-40.04	-40.04	-35.04	-35.04	-40.04	-40.04	-29.16	-30.04	-25.04	-25.04
5500.	7500.	7500.	7000.	7000.	7000.	7000.	7000.	7000.	7000.
7000.	7000.	7000.	7500.	7500.	7500.	7500.	7500.	7500.	7500.
2919.	4828.	4631.	4738.	4532.	5477.	4772.	4144.	3510.	2868.
1978.	1990.	2905.	3734.	2553.	2327.	4488.	3884.	4749.	4625.

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WARM SPRINGS SUPRON PROFILE
DX,ITOTL,NUMCP,MAXIT,ERR : 9766. , 19 ,  2 , 15 , .200
IFLAG1,IFLAG2,IFLAG3,IFLAG4,IFLAG5 :-1 ,-1 , 4 , 2 ,-1
BASEMENT DENSITY IN GM/CC=2.67.
STA  PRISM    FIRST    MEASURD
    NUM  DENS     GUESS    GRAVITY
         CONTRST  DEPTH
     1     -.67   3000.   -215.00       2     -.67   3450.   -215.00
     3     -.67   3000.   -210.00       4     -.67   3000.   -205.00
     5     -.67   3000.   -200.00       6     -.67   3000.   -195.00
     7     -.67   3000.   -195.00       8     -.67   3000.   -200.00
     9     -.67   3000.   -205.00      10     -.67   3000.   -210.00
    11     -.67   3000.   -215.00      12     -.67   3000.   -220.00
    13     -.67   3000.   -220.00      14     -.67   3000.   -215.00
    15     -.67   3000.   -210.00      16     -.67   3000.   -205.00
    17     -.67   3071.   -200.00      18     -.67   3000.   -200.00
    19     -.67   3000.   -205.00
 STATION NUMBER AND DEPTH OF CONSTRAINED POINTS:
    2   3450.
   17   3071.
REGIONAL IN FORM Y=A0+A1*X+A2*(X*X)
Y IS CORRECTION IN MGALS
X IS STATION NUMBER
FOR A LINEAR REGIONAL, "A2" IS ZERO AND
A0 IS THE Y-INTERCEPT AND
A1 IS THE SLOPE. THE ORIGIN IS ONE STATION
POSITION OFF THE END FROM  THE FIRST STATION.
INPUT REGIONAL: A0=     .000      A1=   .000 A2=   .000
 NUMIT= 1    SGRSQ=  1078.000
 NUMIT= 2    SGRSQ=   101.327
 NUMIT= 3    SGRSQ=    63.032
 NUMIT= 4    SGRSQ=    57.945
 NUMIT= 5    SGRSQ=    56.677
 NUMIT= 6    SGRSQ=    56.252
 NUMIT= 7    SGRSQ=    56.084
 NUMIT= 8    SGRSQ=    56.008
 NUMIT= 9    SGRSQ=    55.971
 NUMIT=10    SGRSQ=    55.953
 NUMIT=11    SGRSQ=    55.944
 NUMIT=12    SGRSQ=    55.939
 NUMIT=13    SGRSQ=    55.936
 NUMIT=14    SGRSQ=    55.934
 NUMIT=15    SGRSQ=    55.934
  JOB TERMINATED,
 NUMIT(15 ) EQUALLED MAXIT(15 )
 BEFORE ERROR TOLERANCE WAS REACHED,
 SGRSQ=    55.93      SERRSQ=       .76
FINAL REGIONAL: A0=-179.937     A1=   .000 A2=   .000
4174.,  4068.,  3741.,  2858.,  2214.,  1531.,  1526.,  2195.,  2813.,  3473.,
4144.,  5157.,  5046.,  4160.,  3586.,  2723.,  2453.,  2050.,  2990.,
2,  3450., 17,  3071.,
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DATA TABULATION,

STA NUM	SURFACE ELEV	MEASURD GRAVITY MINUS REGIONAL	COMPUTED GRAVITY	MINUS CALC. GRAV.		MEAS. GRAV. BASEMT	BASEMNT ELEV.	DEPTH TO
1	6000.	-35.06	-35.06	.00	1826.	4174.		
2	5500.	-35.06	-29.78	-5.29	2050.	4068.		
3	5500.	-30.06	-30.06	.00	1759.	3741.		
4	5500.	-25.06	-25.06	.00	2642.	2858.		
5	5500.	-20.06	-20.06	.00	3286.	2214.		
6	5500.	-15.06	-15.06	.00	3969.	1531.		
7	5500.	-15.06	-15.06	.00	3974.	1526.		
8	5500.	-20.06	-20.06	.00	3305.	2195.		
9	5500.	-25.06	-25.06	.00	2687.	2813.		
10	5450.	-30.06	-30.06	.00	1977.	3473.		
11	5400.	-35.06	-35.06	.00	1256.	4144.		
12	5400.	-40.06	-40.06	.00	243.	5157.		
13	5400.	-40.06	-40.06	.00	354.	5046.		
14	5200.	-35.06	-35.06	.00	1040.	4160.		
15	5000.	-30.06	-30.06	.00	1414.	3586.		
16	5000.	-25.06	-25.06	.00	2277.	2723.		
17	5000.	-20.06	-25.35	5.29	1929.	2453.		
18	5000.	-20.06	-20.06	.00	2950.	2050.		
19	5100.	-25.06	-25.06	.00	2110.	2990.		

WARM SPRINGS SUPRON PROFILE

```
 19
-35.06 -35.06 -30.06 -25.06 -20.06 -15.06 -15.06 -20.06 -25.06 -30.06
-35.06 -40.06 -40.06 -35.06 -30.06 -25.06 -20.06 -20.06 -25.06
-35.06 -29.78 -30.06 -25.06 -20.06 -15.06 -15.06 -20.06 -25.06 -30.06
-35.06 -40.06 -40.06 -35.06 -30.06 -25.06 -25.35 -20.06 -25.06
 6000.  5500.  5500.  5500.  5500.  5500.  5500.  5500.  5500.  5450.
 5400.  5400.  5400.  5200.  5000.  5000.  5000.  5000.  5100.
 1826.  2050.  1759.  2642.  3286.  3969.  3974.  3305.  2687.  1977.
 1256.   243.   354.  1040.  1414.  2277.  1929.  2950.  2110.
```

RESISTIVITY WELL LOG CHARACTERISTICS

No. Catalog	Location	Depth range (feet)	Conductance (sie.)
DO 5450K	26-25N-40E	45-3254	979
DO 6902M	16-25N-51E	2009-10964	1406
KO 9235S	10-27N-32E	1220-7959	2037
DO 0085BL	17-37N-29E	1499-7926	2796
KO 7598X	5-41N-52E	76-2223	679
KO 7598Y	5-41N-52E	2227-5186	679
KO 1359S	16-41N-60E	1024-6612	542
DO 6748C	6-17S-57E	598-5472	4.8
KO 5346W	19-3N-60E	160-7683	185
KO 8566I	30-4N-55E	640-8335	175
DO 3564M	22-5N-55E	464-8293	320
D 13488W	2-7N-56E	997-10181	37
DO 3211M	21-7N-66E	2234-11502	336
DO 2458A	24-8N-50E	487-9700	348
DO 4818L	9-12N-57E	602-7084	135
KO 6616W	20-12N-67E	1060-5951	91
DO 5792L	6-13N-48E	100-4666	149
DO 5792M	6-13N-48E	100-4666	149
KO 8881Z	23-14N-60E	0-8148	190
KO 1604X	19-24N-64E	507-8402	734
DO 5365H	5-25N-62E	95-10520	196
DO 2377A	10-29N-55E	1495-10568	1048
DO 2378B	24-29N-55E	1106-11914	785
KO 0418J	8-30N-60E	1010-13111	827
KO 8580L	22-22S-60E	324-6739	69
KO 8581H	16-1S-36E	536-9100	800

No.Catalog	Location	Depth Range (feet)	Conductance
KO 1836P	18-12S-63E	30-7030	15.2
DO 2457D	10-4N-50E	539-9165	821
KO 1000Y	2-7N-61E	860-10450	301
DO 8213G	29-9N-57E	1604-13934	1560
KO 9399F	16-19N-27E	696-8367	928
KO 2635S	29-20N-28E	53-4304	416
DO 7227H	24-22N-58E	120-10343	281
KO 6086Z	23-17N-67E	60-6556	798
DO 3652D	18-20N-50E	2020-9098	720
DO 1548A	1-21N-53E	1072-10567	515

Appendix 2

Program ELOG to calculate Dar Zarrouk parameters from digitized well log resistivity data.

```
C       ELOG.FOR
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C       PROGRAM TO COMPUTE DAR ZARROUK PARAMETERS FROM A
C       LINEARLY SAMPLED RESISTIVITY LOG
C
C       WRITTEN 8-20-1989, GVK
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION R(3000),AV(220),FC(220),PLT(220),DEPTH(220)
     &,TR(220),SPIKE(220),spike2(220)
      CHARACTER*60 A,WELL
 1002 FORMAT(A60)
      WRITE(*,1000)
 1000 FORMAT(1X,'This program does a DAR ZARROUK analysis of',/
     &,'a digitized well log.  You must be prepared to provide',/
     &,'a data file as follows:',/
     &,'       1. A 60 character title.',/
     &,'       2. The number of log samples in strict I4 format',/
     &,'       3. The well log top in feet, readable as F19.9',/
     &,'       4. The sampling interval in feet, also F19.9',/
     &,'       5. Samples, in F19.9, one to a line.')
      WRITE(*,1008)
 1008 FORMAT(1X,'NAME AND PATH OF SAMPLE FILE: ',$)
      READ(*,1002) A
      OPEN(8,FILE=A,STATUS='OLD')
      READ (8,1009) WELL
 1009 FORMAT(A60)
      READ (8,1010) NUMBER
 1010 FORMAT(I4)
      READ (8,1011) D1
 1011 FORMAT(F19.9)
      D1=D1/3.28
      READ (8,1011) DELTA
      DELTA=DELTA/3.28
      DO 1 I=1,NUMBER
    1 READ(8,1011) R(I)
      CLOSE(UNIT=8)
      LEN=NUMBER/110
      N=NUMBER/LEN
      SPAN=FLOAT(LEN)*DELTA
      DO 2 I=1,N
      I2=LEN*I-len/2
      XI2=I2
    2 DEPTH(I)=D1+XI2*DELTA
          CALL AVRES(R,NUMBER,AV,LEN,N)
      OPEN(7,FILE='ELOG.V',STATUS='NEW')
      WRITE(7,2001) WELL
 2001 FORMAT(1X,'SMOOTHED RESISTIVITY LOG ',A60,/)
      WRITE(7,2041) SPAN
 2041 FORMAT(1X,'SPAN OF SMOOTHING OPERATOR IS ',F5.1,' METERS')
      WRITE(7,2007) NUMBER,DELTA
 2007 FORMAT(1X,I4,' Samples were taken at an interval of',
     &f6.2,' meters.',/)
 2002 FORMAT(1X,'DEPTH',2X,'RESISTIVITY')
      WRITE(7,2003)
 2003 FORMAT(1X,'RES=','10**-01',12X,'10**00',13X,'10**01',13X,
     &'10**02',13X,'10**03',13x,'10**04',13x,'10**05',' OHM-M')
      WRITE(7,2013)
 2013 FORMAT(5X,'__________________________________________________',
     &'__________________________________________________________',
     &'_______')
 2004 FORMAT(5X,':',6(18X,':'))
      DO 3 I=1,N
```

```
      CALL DIGIT(AV1,PLT,-19.,96.,I)
      PLT(1)='|'
      IF(PLT(20).EQ.' ') PLT(20)='|'
      IF(PLT(39).EQ.' ') PLT(39)='|'
      IF(PLT(58).EQ.' ') PLT(58)='|'
      IF(PLT(77).EQ.' ') PLT(77)='|'
      IF(PLT(96).EQ.' ') PLT(96)='|'
      PLT(115)='|'
    3 WRITE(7,2005) DEPTH(I),(PLT(J),J=1,115),AV(I)
 2005 FORMAT(F5.0,115A1,E10.3)
      WRITE(7,2013)
      WRITE(7,2003)
      CLOSE(UNIT=7)
      WRITE(*,2006)
 2006 FORMAT(1X,'SMOOTHED E-LOG IS IN FILE ELOG.V')
      ADJ=FLOAT(LEN/2)*DELTA
      DO 31 I=1,N
   31 DEPTH(I)=DEPTH(I)-ADJ
          CALL CUMCON(R,DELTA,PC,LEN,N)
      OPEN (6,FILE='CSLOG.V',STATUS='NEW')
      WRITE(6,3001) WELL
 3001 FORMAT(1X,'CUMULATIVE CONDUCTANCE LOG FOR ',A60,/)
      X1=PC(N)
      WRITE(*,3004)
 3004 FORMAT(1X, 'CUMULATIVE CONDUCTANCE LOG IS IN FILE CSLOG.V')
      WRITE(6,3003) X1
 3003 FORMAT(1X,'TOTAL INTEGRAL CONDUCTANCE IS ',F8.1,' SIEMANS')
      SC=X1/6.
      K0=0
      K1=SC
      SC=2.*SC
      K2=SC
      SC=1.5*SC
      K3=SC
      SC=1.33333*SC
      K4=SC
      SC=1.25*SC
      K5=SC
      SC=1.2*SC
      K6=SC
      WRITE(6,4012) K0,K1,K2,K3,K4,K5,K6
 4012 FORMAT(3X,'S= ',I1,18X,I4,5(15X,I4),'SIEMANS')
      WRITE(6,2013)
      DO 5 I=1,N
      X2=PC(I)/pc(N)
      CALL DIGIT(X2,PLT,0.0,1.0,I)
      PLT(1)='|'
      IF(PLT(20).EQ.' ') PLT(20)='|'
      IF(PLT(39).EQ.' ') PLT(39)='|'
      IF(PLT(58).EQ.' ') PLT(58)='|'
      IF(PLT(77).EQ.' ') PLT(77)='|'
      IF(PLT(96).EQ.' ') PLT(96)='|'
      PLT(115)='|'
    5 WRITE(6,3005) DEPTH(I),(PLT(J), J=1,115),PC(I)
 3005 FORMAT(F5.0,115A1,E10.3)
      WRITE(6,2013)
      WRITE(6,4012) K0,K1,K2,K3,K4,K5,K6
          CALL TRANS(R,DELTA,TR,LEN,N)
      OPEN (5,FILE='TRLOG.V', STATUS ='NEW')
      WRITE(5,4001) WELL
 4001 FORMAT(1X,'TRANSVERSE RESISTANCE LOG FOR ',A60,/)
      X1=tr(N)
      WRITE(5,4021) X1
 4021 FORMAT(1X,'TOTAL TRANSVERSE RESISTANCE IS ',E10.3,' OHMS',/)
      SC=X1/6.
```

```
      SC=2.*SC
      K2=SC
      SC=1.5*SC
      K3=SC
      SC=1.333333*SC
      K4=SC
      SC=1.25*SC
      K5=SC
      SC=1.2*SC
      K6=SC
      WRITE(5,4022) K0,K1,K2,K3,K4,K5,K6
 4022 FORMAT(2X,'T= ',I1,18X,I7,5(12X,I7),' OHMS')
      WRITE(5,2013)
      WRITE(*,4004)
 4004 FORMAT(1X,'TRANSVERSE RESISTANCE LOG IS IN FILE TRLOG.V')
      DO 7 I=1,N
      X2=TR(I)/tr(N)
      CALL DIGIT(X2,PLT,0.0,1.0,I)
      PLT(1)='!'
      IF(PLT(20).EQ.' ') PLT(20)='!'
      IF(PLT(39).EQ.' ') PLT(39)='!'
      IF(PLT(58).EQ.' ') PLT(58)='!'
      IF(PLT(77).EQ.' ') PLT(77)='!'
      IF(PLT(96).EQ.' ') PLT(96)='!'
      PLT(115)='!'
    7 WRITE(5,3005) DEPTH(I),(PLT(J),J=1,115),TR(I)
      WRITE(5,2013)
      WRITE(5,4022) K0,K1,K2,K3,K4,K5,K6
      OPEN(4,FILE='SPIKE.V',STATUS='NEW')
      WRITE(4,5002) WELL
 5002 FORMAT(1X,'Spiked conductance log for ',A60,/)
      WRITE(4,2007) NUMBER, DELTA
      WRITE(4,2013)
          CALL PICKER(PC,SPIKE,N)
      X1=0.0
      X3=0.0
      DO 8 I=1,N
      IF(SPIKE(I).GT.X1) X1=SPIKE(I)
    8 IF(SPIKE(I).LT.X3) X3=SPIKE(I)
      SCALE=X1-X3
      DO 9 I=1,N
      X2=SPIKE(I)/SCALE+1.025
      CALL DIGIT(X2,PLT,0,2.050,I)
      PLT(1)='!'
      IF(PLT(20).EQ.' ') PLT(20)='!'
      IF(PLT(39).EQ.' ') PLT(39)='!'
      IF(PLT(58).EQ.' ') PLT(58)='!'
      IF(PLT(77).EQ.' ') PLT(77)='!'
      IF(PLT(96).EQ.' ') PLT(96)='!'
      PLT(115)='!'
    9 WRITE(4,5001) DEPTH (I),(PLT(J),J=1,115),SPIKE(I)
 5001 FORMAT(1X,F5.0,115A1,E10.3)
      WRITE(4,2013)
      WRITE(*,4444)
 4444 FORMAT(1X, 'SPIKED CS-LOG IS IN FILE SPIKE.V')
      OPEN (3,FILE='SPIKE2.V', STATUS='NEW')
      WRITE(3,6002) WELL
 6002 FORMAT(1X,'Spiked resistance log for ',a60,/)
      write(3,2013)
      CALL PICKER(TR,SPIKE2,N)
      X1=SPIKE2(1)
      X3=SPIKE2(1)
      DO 10 I=2,N
      IF(SPIKE2(I).GT.X1) X1=SPIKE2(I)
   10 IF(SPIKE2(I).LT.X3) X3=SPIKE2(I)
```

```
      DO 11 I=1,N
      X2=SPIKE2(I)/SCALE+1.025
      CALL DIGIT(X2,PLT,0,2.050,I)
      PLT(1)='!'
      PLT(115)='!'
      IF(PLT(20).EQ.' ') PLT(20)='!'
      IF(PLT(39).EQ.' ') PLT(39)='!'
      IF(PLT(58).EQ.' ') PLT(58)='!'
      IF(PLT(77).EQ.' ') PLT(77)='!'
      IF(PLT(96).EQ.' ') PLT(96)='!'
   11 WRITE(3,6001) DEPTH(I),(PLT(J),J=1,115),SPIKE2(I)
 6001 FORMAT(F5.0,115A1,E10.3)
      WRITE(3,2013)
      WRITE(*,3333)
 3333 FORMAT(1X,'SPIKED RESISTANCE LOG IS IN FILE SPIKE2.V')
      WRITE(*,3334)
 3334 FORMAT(1X,'WARNING! Rename files before running ELOG again.',/
     &,'Files are ASCII but must be printed in compressed 132 ',
     &/,'character lines!')
      CLOSE(UNIT=5)
      CLOSE(UNIT=6)
      close(unit=3)
      close(unit=3)
      STOP
      END
C
C
C
C
C
      SUBROUTINE AVRES(R,NUMBER,AV,LENGTH,N)
      DIMENSION R(3000),AV(220)
      DO 2 I=2,N
      AV(I)=0.0
      LEN=LENGTH/2
      JL=LENGTH*(I-1)
      J1=JL-LEN
      J2=JL+LEN
      DO 1 J=J1,J2
    1 AV(I)=AV(I)+R(J)
    2 AV(I)=AV(I)/FLOAT(LENGTH+1)
      AV(1)=0.0
      DO 3 I=1,LEN
    3 AV(1)=AV(1)+R(I)
      AV(1)=AV(1)/FLOAT(LEN)
      RETURN
      END
C
C
C
C
      SUBROUTINE CUMCON(R.DELTA,PC,LENgth,N)
      DIMENSION R(2000),PC(120)
      DO 2 I=1,N+1
      PC(I)=0.0
      JN=LENGTH*I-1
      DO 1 J=1,JN
      IF (R(J).EQ.0.0) R(J)=10.
    1 PC(I)=PC(I)+1./R(J)
    2 PC(I)=PC(I)*DELTA
      RETURN
      END
C
C
C
```

```
      SUBROUTINE DIGIT(X,PLT,X1,X2,ILINE)
      DIMENSION PLT(120)
      CHAR3='-'
      CHAR1=' '
      CHAR2='*'
      DO 1 I=1,115
    1 PLT(I)=CHAR1
      IF(ILINE-25) 3,2,3
    2 DO 22 I=2,114
   22 PLT(I)=CHAR3
      GO TO 9
    3 IF(ILINE-50) 5,4,5
    4 DO 44 I=2,114
   44 PLT(I)=CHAR3
      GO TO 9
    5 IF(ILINE-75) 7,6,7
    6 DO 66 I=2,114
   66 PLT(I)=CHAR3
      GO TO 9
    7 IF(ILINE-100) 9,8,9
    8 DO 88 I=2,114
   88 PLT(I)=CHAR3
    9 CONTINUE
      RANGE =X2-X1
      VALUE=X/RANGE*114.+1.5
      IVALUE =VALUE
      PLT(IVALUE)=CHAR2
      RETURN
      END


      SUBROUTINE TRANS(R,DELTA,TR,LENGTH,N)
      DIMENSION R(3000),TR(220)
      DO 2 I=1,N+1
      TR(I)=0.0
      JN=LENGTH*I-1
      DO 1 J=1,JN
    1 TR(I)=TR(I)+R(J)
    2 TR(I)=TR(I)/DELTA
      RETURN
      END


      SUBROUTINE PICKER (PC,SPIKE,N)
      DIMENSION PC(220),SPIKE(220),PCS(220)
      DO 1 I=3,N-2
    1 PCS(I)=(PC(I-1)+PC(I)+PC(I+1)+PC(I-2)+PC(I+2))/5.
      PCS(1)=PC(1)
      PCS(N)=PC(N)
      PCS(2)=PC(2)
      PCS(N-1)=PC(N-1)
      DO 2 I=3,N-2
    2 SPIKE(I)=PCS(I+1)-2.*PCS(I)+PCS(I-1)
      SPIKE(1)=PCS(2)-2.*PCS(1)
      SPIKE(110)=PCS(109)-PCS(110)
      RETURN
      END
```