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ABSTRACT

Information Theory Inference, better known as the Maximum Entropy Method, is used to infer the lateral density distribution inside the earth. The approach assumes that the earth consists of indistinguishable Maxwell-Boltzmann particles populating infinitesimal volume elements, and follows the standard methods of statistical mechanics (maximizing the entropy function). The GEM 10B spherical harmonic gravity field coefficients, complete to degree and order 36, are used as constraints on the lateral density distribution. The spherically symmetric part of the density distribution is assumed to be known. The lateral density variation is assumed to be small compared to the spherically symmetric part. The resulting information theory density distribution for the cases of no crust removed, 30 km of compensated crust removed, and 30 km of uncompensated crust removed all give broad density anomalies extending deep into the mantle, but with the density contrasts being the greatest towards the surface (typically ± 0.004 g cm^{-3} in the first two cases and ± 0.04 g cm^{-3} in the third). None of the density distributions resemble classical organized convection cells. The information theory approach may have use in choosing Standard Earth Models, but, the inclusion of seismic data into the approach appears difficult.

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INTRODUCTION

The problem addressed here is inferring via information theory the lateral density variation inside the earth from the observed external anomalous gravity field. Information theory is used because it is the least subjective way to deal with inverse problems (Baierlein, 1971). The motivation for this study is the relationship of the lateral density variation to tectonics and convection.

The nature of the problem is the following. The lateral density variation inside the earth generates the observed gravity anomalies. Hence information about the lateral density variation is provided by examining the anomalies. However, the observed gravity anomalies cannot be inverted to recover the actual density variation. The problem is nonunique: there are an infinite number of density distributions which can generate the observed gravity field. This is unfortunate, since it is desirable to know the lateral density variation, especially with regard as to how it relates to tectonics and convection (Phillips and Lambeck, 1980).

The nonuniqueness can be dealt with by various approaches in order to obtain insight into the physics of the earth. Of these modeling is by far the most common approach. Here extra assumptions are introduced until the solution to the problem becomes unique. Kaula (1963), for instance, assumes that the shear strain energy of the mantle is minimized. This key assumption, and other minor ones, together with the constraints of the observed gravity field determine a unique lateral density variation. Phillips and Lambeck (1981) review many papers which use modeling. Another approach is the Backus-Gilbert method (Backus and Gilbert, 1967, 1968; Parker, 1977), which studies all possible solutions consistent with the given data. This study is called the geophysical inverse problem (Backus and Gilbert, 1967, p. 249). The Backus-Gilbert method has been used

extensively in seismology (e.g., Jordan and Franklin, 1971). Burkhard and Jackson (1976) apply the method to gravity data. There are also other approaches to data inversion; see, e.g., Parker (1977), Sabatier (1977), and references contained therein.

The approach to the lateral density variation used here is that of information theory (Jaynes, 1957, 1963, 1967). This approach is commonly known as the Maximum Entropy Method, or MEM for short. A better name would be Information Theory Inference (ITI for short), since information theory is its basis and the name avoids confusion with thermodynamic entropy (Baierlein, 1971, pp. 473-478). It will be called ITI here.

ITI is a probabilistic approach to nonuniqueness. Each possible answer (labelled i) to a non-unique problem is assigned a probability P_i that it is the correct answer. The probabilities P_i are assigned numerical values so as to maximize Shannon's (1948) information measure

$$MI = -\sum_i P_i \ln P_i \qquad (1)$$

subject to the constraints of the known data. MI in (1) stands for "Missing Information," i.e., the amount of information needed to determine which answer is correct (Baierlein, 1971, p. 64). In practice the expectation value of the desired unknown quantity is taken as the inferred answer to the problem. The information theory approach thus provides a solution to what will be called the geophysical inference problem: picking one answer out of a number of possible answers as the most likely to be true. ITI may hence be regarded as a complementary method to the Backus-Gilbert method (Gull and Daniell, 1978), which investigates the geophysical inverse problem. The rationale for using ITI is that it picks the "best" answer, dictated by the information at hand, out of the many possible answers. "Best" here means "least subjective," i.e. the number of unconscious assumptions in choosing an answer is minimized (Tribus and Rossi, 1973). See Baierlein (1971, pp. 11-89) for an excellent introduction to ITI.

ITI (or MEM) has been used with great success in several different fields. One is statistical mechanics (Jaynes, 1957; Tribus, 1961; Katz, 1967; and Baierlein, 1971). In fact, (1) is the entropy function of statistical mechanics. The only difference between ITI and statistical mechanics lies in ITI's powerful information theory foundation, which allows the approach to be applied to a wide variety of problems, and not just to statistical mechanics. It has been so applied to spectral analysis (Burg, 1967, 1968, 1972) and to radio brightness maps of the sky (Gull and Daniell, 1978). In solid earth geophysics ITI has been applied to the spectral analysis of polar motion (e.g., Smylie et al., 1973; Graber, 1976), and to the radial density distribution of the earth (Rietsch, 1977; Rubincam, 1978, 1979; Graber, 1977) and of the planets (Koyama, 1979).

The present work is an extension of Rubincam (1979) to the lateral density variation. ITI is used to infer the lateral density structure based on the spherical harmonic coefficients of the gravity field and on an assumed spherically symmetric density distribution (also called the radial density distribution). The gravity field coefficients are those of GEM 10B (Lerch et al., 1981), complete to degree and order 36. The hydrostatic equilibrium bulge is subtracted out of the $\ell = 2,4$, $m = 0$ terms using the hydrostatic coefficients of Nakiboglu (1979). Also subtracted from the GEM 10B terms when the need arises are the gravity field coefficients of a crustal model. Two different crustal models are used: one a 30 km-thick isostatically compensated crust and the other an isostatically uncompensated crust, also 30 km thick. Carl Wagner supplied the spherical harmonic coefficients for these models (Wagner, private communication, 1976). Both sets of coefficients are complete to degree and order 36. The radial density distribution is the average structure Parametric Earth Model (PEM) of Dziewonski et al., (1975). Further, the earth is assumed to be a sphere and that the lateral density variation is small compared to the radial density distribution.

The principal results are as follows. The information theory density distribution can be written as a spherical harmonic expansion. The equation for the density variation is similar in form

to that of the equation which gives density contrasts due to lateral temperature differences. For the cases where no crust or the 30 km thick compensated crust is removed the density contrasts are greatest near the earth's surface and have typical magnitudes of ± 0.004 g cm^{-3}. The density contrasts are also greatest near the surface for the case of 30 km of uncompensated crust removed and are typically a factor of 10 larger than in the two other cases. In all three cases the density contrasts decrease with depth but significant density anomalies still extend deep into the mantle. None of the three density distributions look like classical convection patterns, i.e., organized cells with columns of low density where material is rising and columns of high density where material is sinking. No attempt has been made in any of the cases to compute stresses or stress-differences.

DERIVATION OF THE INFORMATION THEORY DENSITY DISTRIBUTION

The information theory density distribution is derived from the following considerations. It is first assumed that the data consist of the known values F_q for Q integrals of the form

$$F_q = \int_V \rho(\vec{r})\, f_q(\vec{r})\, dv, \quad (q = 1, 2, \ldots, Q), \tag{2}$$

where $\rho(\vec{r})$ is the earth's density distribution, $f_q(\vec{r})$ is a function which depends on position $\vec{r}$ inside the earth, dv is a volume element, and V is the volume of the earth. Examples of integrals of this form are the mass and moment of inertia of the earth. The gravity field coefficients also have this form, since they can be written (Phillips and Lambeck, 1980, p. 30)

$$\bar{C}_{\ell mi} = \frac{\int_V \rho(\vec{r})\, r^{\ell}\, \bar{Y}_{\ell mi}(\theta,\lambda)\, dv}{(2\ell+1)\, M_E\, a_E^{\ell}} \tag{3}$$

where $\bar{C}_{\ell m1} = \bar{C}_{\ell m}$ and $\bar{C}_{\ell m2} = \bar{S}_{\ell m}$ are the normalized coefficients of degree ℓ and order m, $r = |\vec{r}|$, and the $\bar{Y}_{\ell mi}(\theta,\lambda)$ are surface spherical harmonics using Kaula's (1967) 4π normalization,

with θ being colatitude and λ longitude. M_E and a_E are the mass and radius of the earth, respectively. Obviously in this case $F_q = \bar{C}_{\ell m i}$ and

$$f_q(\vec{r}) = \frac{r^\ell \bar{Y}_{\ell m i}(\theta,\lambda)}{(2\ell+1)\, M_E\, a_E^\ell} \tag{4}$$

The next consideration in using ITI is to set up the earth models which constitute the various possible answers to the problem. The task is then to choose the "best" model based on the data of the form (2). The earth models are set up as follows: the earth is divided up into infinitesimal cubes, all with equal volume dv = dxdydz. Each cube is labelled with the running subscript j. The position vector from the center of the earth to the jth cube is $\vec{r}_j$. The cubes are populated with indistinguishable particles of mass m. Each earth model i has n_{ji} particles in the jth cube where n_{ji} is an integer ≥ 0. The density of the earth at position $\vec{r}_j$ in the i th model is then $\rho_i(\vec{r}_j) = n_{ji} m/dv$. The integrals (2) for each earth model i become the sums

$$F_{qi} = \sum_j \left(\frac{n_{ji} m}{dv}\right) f_q(\vec{r}_j)\, dv = m \sum_j n_{ji} f_q(\vec{r}_j). \tag{5}$$

The expectation values

$$\langle F_q \rangle = \sum_i P_i F_{qi} \tag{6}$$

are assumed to constitute the observed values of F_q, where P_i is the probability that the ith model is in fact the correct model.

The problem so formulated is analogous to the standard statistical mechanics problem of determining the population numbers of indistinguishable particles following Bose-Einstein statistics using the grand canonical ensemble (Rubincam, 1979). (Indistinguishable particles are chosen since the interchanging of particles does not affect the density distribution, which is the topic under discussion.) The solution can thus be carried out in the usual statistical mechanics fashion

(Morse, 1969, pp. 316-319; Reif, 1965, pp. 346-349). (1) is maximized subject to the constraints of the data (6) and $\sum_i P_i = 1$:

$$\frac{\partial}{\partial P_i}\left[-\sum_i P_i \ln P_i + \alpha_0 \sum_i P_i + \alpha_1 \sum_i P_i F_{1i} + \ldots + \alpha_Q \sum_i P_i F_{Qi}\right] = 0$$

where $\alpha_0, \ldots, \alpha_Q$ are Lagrange multipliers, yielding $P_i = \exp(\sum_q \alpha_q F_{qi})/Z$, where

$$Z = e^{1-\alpha_0} = \sum_i \exp\left(\sum_q \alpha_q F_{qi}\right) \tag{7}$$

is the grand partition function. Using (5) in (7) gives

$$Z = \sum_i \exp\left[\alpha_1 \sum_j n_{ji} f_1(\vec{r}_j) + \ldots + \alpha_Q \sum_j n_{ji} f_Q(\vec{r}_j)\right] \tag{8}$$

for Z, where $m\alpha_q$ has been redefined as α_q. Note that the partial derivative of the logarithm of (8) with respect to $\alpha_1 f_1(\vec{r}_j)$ gives

$$\frac{\partial \ln Z}{\partial(\alpha_1 f_1(\vec{r}_j))} = \sum_i n_{ji} \exp\left[\alpha_1 \sum_j n_{ji} f_1(\vec{r}_j) + \ldots + \alpha_Q \sum_j n_{ji} f_Q(\vec{r}_j)\right]$$

$$= \sum n_{ji} P_i = \langle n_j \rangle \tag{9}$$

which is the expectation value of the number of particles in the cube at position $\vec{r}_j$. This result will be used shortly.

If there are no limits to the number of particles occupying each cube, then (8) can be factored as (Morse, 1969, p. 326; Reif, 1965, p. 347)

$$Z = \prod_j Z_j$$

where

$$Z_j = \sum_{n_j=0}^{\infty} \exp\left\{\left[\alpha_1 f_1(\vec{r}_j) + \ldots + \alpha_Q f_Q(\vec{r}_j)\right] n_j\right\} \tag{10}$$

But this has the form $\sum_{n=0}^{\infty} x^n$, which is equal to $1/(1-x)$. Hence (10) becomes

$$Z_j = \frac{1}{1-\exp\left[\alpha_1 f_1(\vec{r}_j) + \ldots + \alpha_Q f_Q(\vec{r}_j)\right]} \tag{11}$$

Therefore

$$\langle n_j \rangle = \frac{1}{e^{-\alpha_1 f_1(\vec{r}_j) - \ldots - \alpha_Q f_Q(\vec{r}_j)} - 1} \tag{12}$$

by (9). If it is now assumed that $\langle n_j \rangle << 1$, so that the Bose-Einstein statistics pass over to Maxwell-Boltzmann statistics (Reif, 1965, p. 352; Morse, 1969, p. 329), then the exponential term in the denominator of (12) is much greater than 1, and (12) simplifies to

$$\langle n_j \rangle \approx e^{\alpha_1 f_1(\vec{r}_j) + \ldots + \alpha_Q f_Q(\vec{r}_j)}$$

Multiplying this by m/dv and dropping the subscript j gives the expression

$$\rho_1(\vec{r}) = \frac{m}{dv} \langle n_j \rangle = \frac{m}{dv}\, e^{\alpha_1 f_1(\vec{r}) + \ldots + \alpha_Q f_Q(\vec{r})} \tag{13}$$

as the information theory density distribution. This is a most important result: it gives the form of the information theory density distribution for particles following Maxwell-Boltzmann statistics where the constraints on the density distribution have the form (2). The variance of the distribution is discussed in Appendix A.

The m/dv appearing in (13) is a troublesome factor. No commitment has been made either to the value of m or dv; and there seems to be no clear guidance on how to choose their values. As it turns out, this problem may be avoided by absorbing the factor into the spherically symmetric part of the density distribution, as shown next.

The task now is to simplify (13). This involves two assumptions: first, that $f_1(\vec{r})$ pertains solely to the spherically symmetric part of the density distribution (explained below); and second, that

$$|\alpha_2 f_2(\vec{r}) + \ldots + \alpha_Q f_Q(\vec{r})| \ll 1$$

so that

$$e^{\alpha_2 f_2(\vec{r}) + \ldots + \alpha_Q f_Q(\vec{r})} \cong 1 + \alpha_2 f_2(\vec{r}) + \ldots + \alpha_Q f_Q(\vec{r})$$

where the $f_2(\vec{r}), \ldots, f_Q(\vec{r})$ are the appropriate functions (4) for the gravity field (i.e. the anomalous density variation is small compared to the radial density.) With these two assumptions (13) becomes

$$\rho_1(\vec{r}) \cong \frac{m}{dv}\, e^{\alpha_1 f_1(\vec{r})} \left[1 + \sum_{\ell mi} \frac{\alpha_{\ell mi}\, r^\ell\, \bar{Y}_{\ell mi}(\theta,\lambda)}{(2\ell+1) M_E a_E^\ell} \right]$$

which may be written

$$\rho_1(\vec{r}) \cong \rho_o(r) + \sum_{\ell mi} \frac{\alpha_{\ell mi}\, \rho_o(r)\, r^\ell\, \bar{Y}_{\ell mi}(\theta,\lambda)}{(2\ell+1) M_E a_E^\ell} \tag{14}$$

where

$$\rho_o(r) = \frac{m}{dv}\, e^{\alpha_1 f_1(\vec{r})} \tag{15}$$

with $\rho_o(r)$ being the spherically symmetric part of $\rho(\vec{r})$ and where subscripts ℓmi have been substituted for subscript q. Obviously taking $f_1(\vec{r})$ to be

$$f_1(\vec{r}) = \frac{1}{\alpha_1}\, \ln\, [\rho_o(r) dv/m]$$

results in (15). This is artificial, to be sure; no value F_1 in (2) is known for the earth where $f_1(\vec{r})$ has the form given above. However, it has two advantages: the troublesome factor m/dv disappears, and any desired $\rho_0(r)$ can be used in (14). The $\rho_0(r)$ for the earth is known to a high degree of accuracy from other data: it cannot differ greatly from the PEM $\rho_0(r)$ of Dziewonski et al., (1975). Hence it will be assumed here that the integral F_1 is known for the earth where $f_1(\vec{r})$ is given by the above equation, in order to use Dziewonski et al.'s (1975) radial density distribution.

All that remains to find the information theory density distribution is to evaluate the $\alpha_{\ell mi}$ using the gravity field coefficients. The raw gravity field coefficients given by (2) will not be used, however, for two reasons. The first reason is that the contribution of the earth's hydrostatic equilibrium rotational bulge to the gravity field must be subtracted out. The second reason is that the gravity field of the crust must also be subtracted from the coefficients when a crustal model is used. In this case the gravity field data become

$$\hat{C}_{\ell 01} = \bar{C}^{GEM}_{\ell 01} - \bar{C}^{CR}_{\ell 01} - \bar{C}^{HE}_{\ell 01}$$

for the ℓ = even, m = 0, i = 1 terms and

$$\hat{C}_{\ell mi} = \bar{C}^{GEM}_{\ell mi} - \bar{C}^{CR}_{\ell mi}$$

for the other coefficients. The superscripts GEM, HE, and CR stand for "Goddard Earth Model," "Hydrostatic Equilibrium," and "Crust" respectively. Actually only the $\ell = 2$ and $\ell = 4$ hydrostatic equilibrium coefficients computed by Nakiboglu (1979) for Dziewonski et al.'s (1975) PEM will be used here; the higher degree hydrostatic equilibrium terms are assumed to be zero. Strictly, these terms should be included, but their computation is difficult and the error in ignoring them is probably small. All of the crustal terms up to and including degree and order 36 will, however, be subtracted from the GEM 10B coefficients when a crustal model is used.

Substituting (14) for $\rho(\vec{r})$ and $\hat{C}_{\ell mi}$ for $\bar{C}_{\ell mi}$ into (2) to evaluate the $\alpha_{\ell mi}$ yields

$$\rho_I(\vec{R}) = \rho_o(R)\left[1 + \sum_{\ell mi} \delta_\ell \hat{C}_{\ell mi} R^\ell \bar{Y}_{\ell mi}(\theta,\lambda)\right] \tag{16}$$

as the information theory density distribution, where the

$$\delta_\ell = \frac{(2\ell+1)\,\bar{\rho}_E}{3\int_o^{R_U} \rho_o(R)\, R^{2\ell+2}\, dR} \tag{17}$$

are found by using the orthogonality properties of the $\bar{Y}_{\ell mi}(\theta,\lambda)$, where the earth is assumed to be a sphere, and where the variable r has been replaced by $R = r/\bar{a}_E$ for convenience so that $0 \leq R \leq 1$. Also, $\bar{\rho}_E$ is the average density of the earth and $\bar{a}_E = 6371$ km is the radius of the earth. R_U is the radius of the sphere in which the unknown density distribution to be inferred resides (the subscript u standing for "Upper.") For example, $R_U = 1$ if no crust is stripped off the earth and $R_U = 6341/6371$ if a 30 km thick crust is stripped off. The integral in the denominator of (17) can be evaluated analytically, since Dziewonski et al. (1975) break up the earth into eight shells, with $\rho_o(R)$ being given as a polynomial in R in each shell. Table 1 gives the δ_ℓ resulting from this computation for $R_U = 1$ and for $R_U = 6341/6371$.

RESULTS AND COMPARISONS WITH OTHER STUDIES

The fundamental equations of this paper are (16) and (17). What they give is, in a sense, the broadest possible density anomalies; more localized anomalies are not warranted by the data. Some general features of these equations should be noted before examining specific density distributions.

The information theory density distribution $\rho_I(\vec{r})$ (the subscript I standing for "Information Theory") given by (16) is obviously a spherical harmonic expansion of the form

$$\rho_I(\vec{r}) = \rho_o(R) + \Delta\rho_I = \rho_o(R) + \sum_{\ell mi} \bar{\rho}_{\ell mi}(R)\, \bar{Y}_{\ell mi}(\theta,\lambda) \tag{18}$$

where

$$\Delta\rho_I = \sum_{\ell m i} \bar{\rho}_{\ell m i}(R)\, \bar{Y}_{\ell m i}(\theta,\lambda), \quad \bar{\rho}_{\ell m i}(R) = \delta_\ell\, C_{\ell m i}\, R^\ell \rho_o(R). \tag{19}$$

Note that $\Delta\rho_I$ changes discontinuously when $\rho_o(R)$ does. Also, (16) has a form similar to that of the equation giving a density variation due to lateral temperature differences (e.g. Phillips and Lambeck, 1980, p. 32):

$$\rho = \rho_o\,[1 - \alpha(T - T_o)] \tag{20}$$

Here α is the coefficient of thermal expansion, ρ_o and T_o are the reference density and reference temperature, respectively, while T is the temperature. (The reason (16) has this form is due to the assumption that $\Delta\rho_I$ is small compared to $\rho_o(R)$). So (16) is consistent with the idea that the density anomalies are due to lateral temperature differences—but does not necessarily imply that the anomalies are so caused.

It should further be noted that there is no point in computing the power spectrum of the anomalous potential $V_\ell^2(\Delta U)$ (e.g. Phillips and Lambeck, 1980, equation 11) generated by the density distribution (16), since the field coefficients are the given data, which (16) automatically satisfy. Moreover, the information theory density distribution (16) does not have a white noise spectrum, which Lambeck (1976) (see also Phillips and Lambeck, 1980) found will reproduce the observed anomalous potential spectrum (i.e. Kaula's (1967) rule-of-thumb). Instead the information theory density distribution $\rho_I(\vec{R})$ concentrates the density anomalies towards the earth's surface, due to the R^ℓ behavior of $\bar{\rho}_{\ell m i}(R)$ and the ℓ^2 behavior of δ_ℓ in (19). (The ℓ^2 behavior may be seen by substituting $\bar{\rho}_E$ for $\rho_o(R)$ in (17) and evaluating the integral.) Also, it is clear from (19) that the lower degree anomalies are spread more evenly throughout the earth than the higher degree anomalies. This concentration of density anomalies towards the surface is in contrast to the findings of the Monte Carlo studies of Kaula (1977) and the mass-point studies of Lowrey (1978),

who indicate that the anomalies may increase with depth. Dziewonski et al. (1977) and Julian and Sengupta (1973), among others, also indicate that large anomalies are to be found deep within the mantle on the basis of seismic travel time studies. The statistical gravity study of Khan (1977), however, places most of the anomalies in the upper mantle. The seismic studies of Romanowicz (1979) and Cara (1979) and others show considerable upper mantle lateral structure, while the analysis of satellite-to-satellite tracking data by Marsh et al. (1981) indicates that most of the gravity anomalies in the Pacific can be explained by lithospheric sources.

It should be mentioned that the density anomalies given by (16) and (17) are not confined to the crust and mantle, but extend into the core as well. To exclude them from the core the lower limit of the integral in (17) would have to be replaced by R_L (the subscript L standing for "Lower"), where $R_L = 3485.7/6371.0$, the radius of the core being 3485.7 km. In practice excluding the density anomalies from the core makes little difference in the resulting density distribution for the crust and mantle. Finally, the boundaries where $\rho_0(R)$ changes discontinuously are assumed to be spherical, so that there is no possibility of density anomalies arising from bumps on these boundaries in the manner of Hide and Horai (1968) and McQueen and Stacey (1976), for example.

The above constitute the general remarks on the information theory density distribution. Specific examples are discussed next.

A computer program was written to produce maps in order to examine specific information theory density distributions.* All of the maps are based on the GEM 10B gravity field (Lerch et al., 1981). The GEM 10B field is based on satellite, surface gravity, and GEOS-3 altimetry data. Since GEM 10B is complete to degree and order 36, the limit of resolution is about 5 degrees of arc, or about 550 km on the earth's surface. All of the higher degree terms ($\ell \gtrsim 16$) are assumed to be meaningful, although Phillips and Lambeck (1980, p. 44) warn that these terms may largely be noise.

*See Appendix B for a listing of the program.

Plate 1 shows the density variation $\Delta\rho_1$ given by (19) overlaid on the global tectonic and volcanic activity map of Lowman (1981). The density variation is given on the surface of a sphere with radius 6368.0 km. It is at this depth, 3 km, that the oceans leave off and the rock surface begins in Dziewonski et al.'s (1975) PFM. No crust has been stripped off. The interval between contour lines is 0.002 g cm^{-3}. This map looks quite similar to the GEM 10B free-air gravity anomaly map (S. Klosko, private communication, 1980). It shows such typical features as the lows at Hudson Bay, Fennoscandia and some of the abyssal plains (e.g., Somali, Hatteras); and highs at some slow-moving ocean ridges (e.g., Mid-Atlantic, Southwest Indian Ocean), subduction zones (e.g., Peru-Chile, Tonga-Kermadec), and hot spots (e.g., Hawaii, Iceland). Hence for qualitatively relating density and tectonics, similar to relating gravity to tectonics as done by Kaula (1972), a free-air gravity anomaly map might just as well be used.

The map shows regions of artificial densities, due to the assumption that the earth is a sphere; the topography has been flattened. So at the Mid-Atlantic Ridge south of Iceland, for example, the effect of topography more than cancels the effect of the low density material upwelling beneath the ridge (assuming the basic validity of plate tectonics), producing a positive anomaly (Lambeck, 1972) and hence an artificially high density.

Plate 2 shows the density distribution at 30 km depth ($r = 6341$ km), where 30 km of isostatically uncompensated crust has been stripped off the earth (giving essentially the Bouguer anomalies). The interval between contour lines is 0.02 g cm^{-3}. Note that it gives low densities at some subduction zones. Removing the Andes, for example, completely erases the positive anomaly of Plate 1, so that low densities prevail. There is no sign of a high density subducting slab (which is probably too small to be seen in any case with the resolution employed here).

Figures 1, 2, and 3 show $\Delta\rho_1$ on a plane which slices through the center of the earth in the equatorial plane for the cases of no crust removed, 30 km of isostatically compensated crust removed, and 30 km of isostatically uncompensated crust removed, respectively. The equatorial plane was

chosen because it illustrates typical features of such slices, plus one atypical feature which appears in Figure 2.

All three figures illustrate a remark made earlier: that the information theory density anomalies extend deep into the earth, but the greatest density variation occurs near the surface. This is in qualitative agreement with Arkani-Hamed's (1970) minimum shear strain energy density distribution, but his density anomalies are much larger than those shown here. The figures also show regions where $\Delta\rho_1$ changes sign with depth. This is also in qualitative agreement with Sanchez's (1980) density distribution which minimizes the sum of the mantle shear strain energy plus gravitational potential energy. The size of the density variation shown in Figures 1 and 2 is in fair agreement with Sanchez (1980). However, the density distribution across Sanchez's (1980) slice through the equatorial plane looks nothing like those shown in the figures. It should be mentioned that the minimum energy solutions of Kaula (1963), Arkani-Hamed (1970), and Sanchez (1980) give nonhydrostatic stresses which probably exceed the finite strength of the mantle, indicating that the assumed elastic rheology is unrealistic (Lambeck, 1976, p. 6333). The alternation of the sign of $\Delta\rho_1$ with depth is also in qualitative agreement with Lewis and Dorman (1970), who used a communications theory approach to the relation of density to topography.

The information theory density distributions shown in Figures 1 to 3 clearly tend to form "pockets" of high and low density extending downwards from the surface. There is no obvious convection pattern shown in any of the figures. None of them show what look like classical convection cells; that is, organized columns of low density material moving upwards and columns of high density material moving downwards. Pockets which slant at an angle to the local normal (such as the low density region at 305 degrees east longitude shown in Figure 2, for example) look like they might indicate some sort of horizontal as well as vertical motion of material. But closer examination of the region around such features generally reveals that there are other pockets of similar density slanting towards them (as is obvious with the two low density pockets between 60

and 90 degrees east longitude shown in Figure 1, for example) which are not contoured. Hence the apparent "motion" is probably an artifact of the contouring process.

The one atypical feature mentioned earlier is the high density "blob" located at 285 degrees east longitude shown in Figure 2. Closer examination of this feature shows that it is a "tube" of high density material connecting the Peru-Chile Trench with the Middle America Trench. This feature is atypical in that the greatest density contrast occurs beneath the surface, while with the pockets the greatest density contrast occurs at the surface of the sphere inside which the density distribution is inferred.

Figures 1 and 2 are quite similar to each other. The reason for this is that the removal of a 30 km-thick isostatically compensated crust affects mostly the high degree spherical harmonic terms, and not the low degree terms considered here. The density distribution shown in Figure 3 is of course dominated by the removal of the uncompensated topography, and not the GEM 10B gravity field.

If the density anomalies of Figures 1 and 2 are assumed to be due to lateral temperature variation, then typical temperature differences of 100 K are required, assuming α in (20) is about 3×10^{-5} K^{-1} (e.g., Phillips and Lambeck, 1980, p. 53). The temperature differences must be about a factor of 10 greater to explain the density anomalies of Figure 3, assuming the same value for α.

Maps showing the density distribution with the degree of the gravity and crustal fields restricted to $\ell \leq 16$ also give pockets similar to those shown in the figures. Hence it appears that the qualitative behavior of the information theory density distribution will not change if terms of higher degree ($\ell > 36$) than those considered here are included in the fields.

DISCUSSION

One question which arises is which of the three density distributions considered here is to be preferred. Obviously the one in which no crust is removed is over-abstracted: no account is taken of the topography. So it is not the preferred density distribution. The density distribution in which 30 km of uncompensated crust is removed has intriguing consequences for the deep structure of continents (e.g., Jordan, 1975; but see Anderson, 1979): very deep indeed. However, the geophysical evidence favors the density distribution in which 30 km of compensated crust is removed; so it is preferred. But it is not ideal: it assumes that the topography is isostatically supported everywhere over the earth; and, moreover, with a depth of compensation of 30 km. This is certainly not the case. To cite just one example where the assumptions fail, no account is taken of thermal isostacy at the ocean ridges (Haxby and Turcotte, 1978), where the effective depth of compensation is greater than 30 km. Hence the density distribution still gives a high density for the Mid-Atlantic Ridge south of Iceland, for example, after the crust is removed, when it should be low density. Hence better models of the crust are needed in order to use ITI to infer the density distribution below it.

Another question which arises is why the information theory density distribution disagrees with the results of Lambeck (1976), Kaula (1977), and Lowrey (1978) which are also based solely on the relationship of density to gravity (and not on seismic travel times), and which give large density anomalies in the lower mantle. The answer appears to be that these studies examine only a limited number of models which mimic the external gravity field, while the information theory density distribution is a weighted average over all possible density models and reproduces the external gravity field exactly.

The reason why the information theory density distribution disagrees with the seismic evidence of Julian and Sengupta (1973), Dziewonski et al. (1977) and others, which also give large anomalies in the lower mantle, seems clear enough: the seismic data have not been included in the information theory approach. Their inclusion presumably would show large anomalies in the lower mantle.

The dominant impression from the foregoing remarks on the problem addressed here is one of simplicity. More data must be introduced to obtain results which are closer to the actual state of affairs inside the earth. Taking the earth to be made up of indistinguishable particles following Maxwell-Boltzmann statistics is an obviously simplifying, if fundamental assumption which must also be dealt with in order to obtain more realistic results.

Introducing seismic travel times into the approach appears to be an obvious next step to take in examining the density anomalies. However, including the seismic travel time data into ITI appears to be difficult. It is not obvious how to put such information into an approach which sums over all possible models. Numerical models are out of the question: dividing up the earth into 10 volume elements each of which may be occupied by up to 10 particles gives 10^{10} models to consider -- far too many already for a computer. Thus the problem must be done analytically. But even such a seemingly simple task as using free oscillation periods to obtain a spherically symmetric earth model has analytical difficulties: the data do not have the simple form (2), and the elastic parameters vary as well as the density. These difficulties make the evaluation of the partition function Z troublesome (Graber, 1977). The variance (see Appendix A) and choosing m/dv in (13) also post difficulties in applying ITI.

On the positive side is the heart of the method: ITI (MEM) minimizes subjectivity. To illustrate, there is no need in ITI to decide which lower degree harmonics to ignore in examining density anomalies in the lithosphere (e.g., Marsh et al., 1981), which is a highly subjective procedure. ITI weights all the harmonics automatically. And since ITI gives the one "best" (i.e., least subjective) model, it may well have use in choosing a Standard Earth Model, although the mathematical obstacles mentioned earlier would have to be overcome.

ACKNOWLEDGMENTS

I wish to thank David E. Smith for many helpful discussions and other valuable assistance. Discussions with Mike Graber were also very useful. Carl Wagner supplied the crustal models and the rock-equivalent topography. I thank Barbara Putney and Tom Odt for programming help. The support of the Director's Discretionary Fund of the Goddard Space Flight Center is gratefully acknowledged. The Technical Memorandum of Rubincam (1979) was erroneously numbered 80549. It should be 80586.

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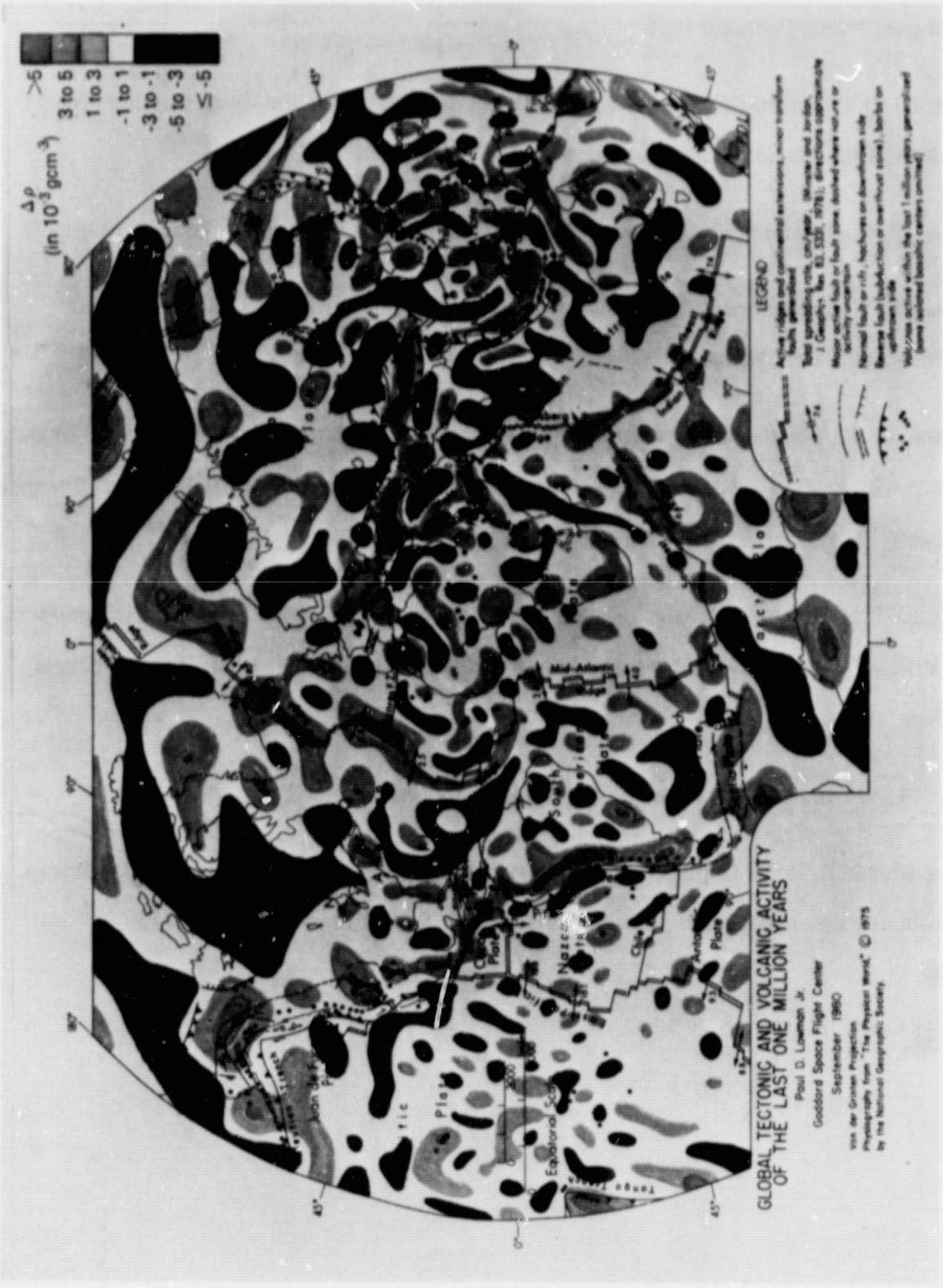

Plate 1. Lateral density variation $\Delta\rho_l$ at 3 km depth (no crust removed). Note that no zero line is shown, which would make the map too busy.

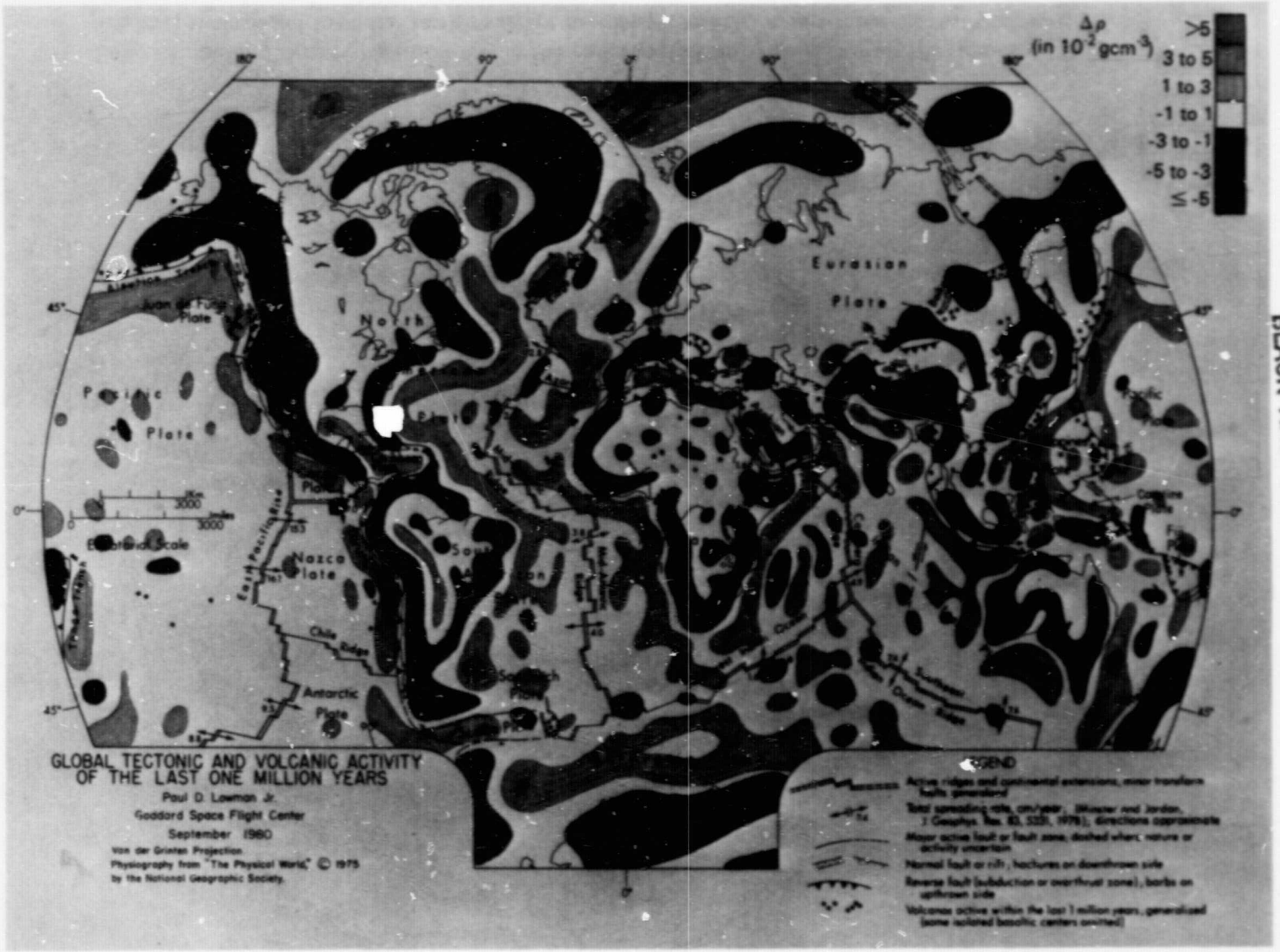

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Plate 2. Lateral density variation $\Delta\rho_1$ at 30 km depth for 30 km of uncompensated crust removed. Note that no zero line is shown, which would make the map too busy.

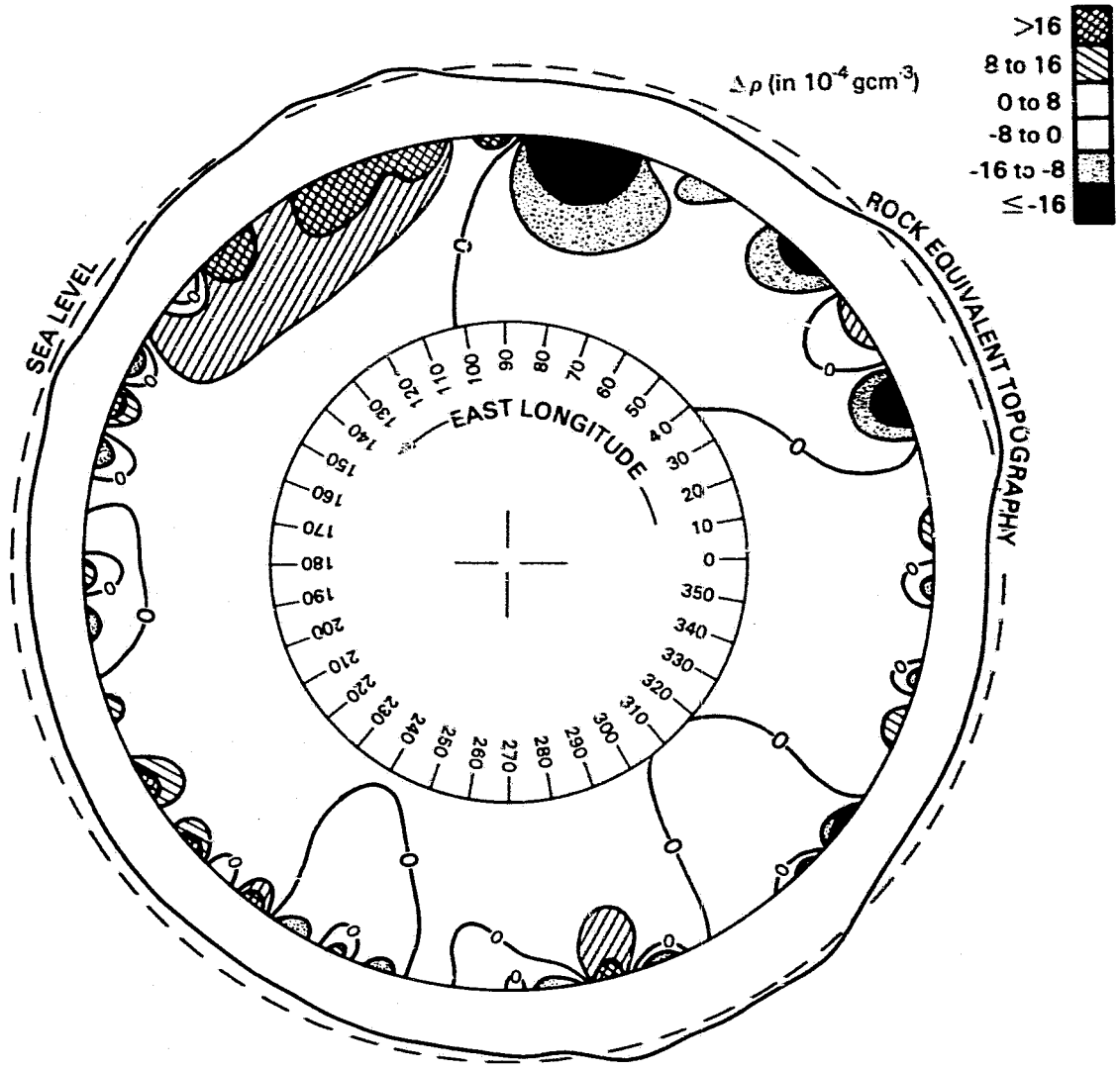

Figure 1. Lateral density variation $\Delta\rho_I$ in the equatorial plane of the earth for the case of no crust removed. Sea level is displaced from the earth's surface for clarity, and the rock-equivalent topography is greatly exaggerated. Anomalies in the core are not shown.

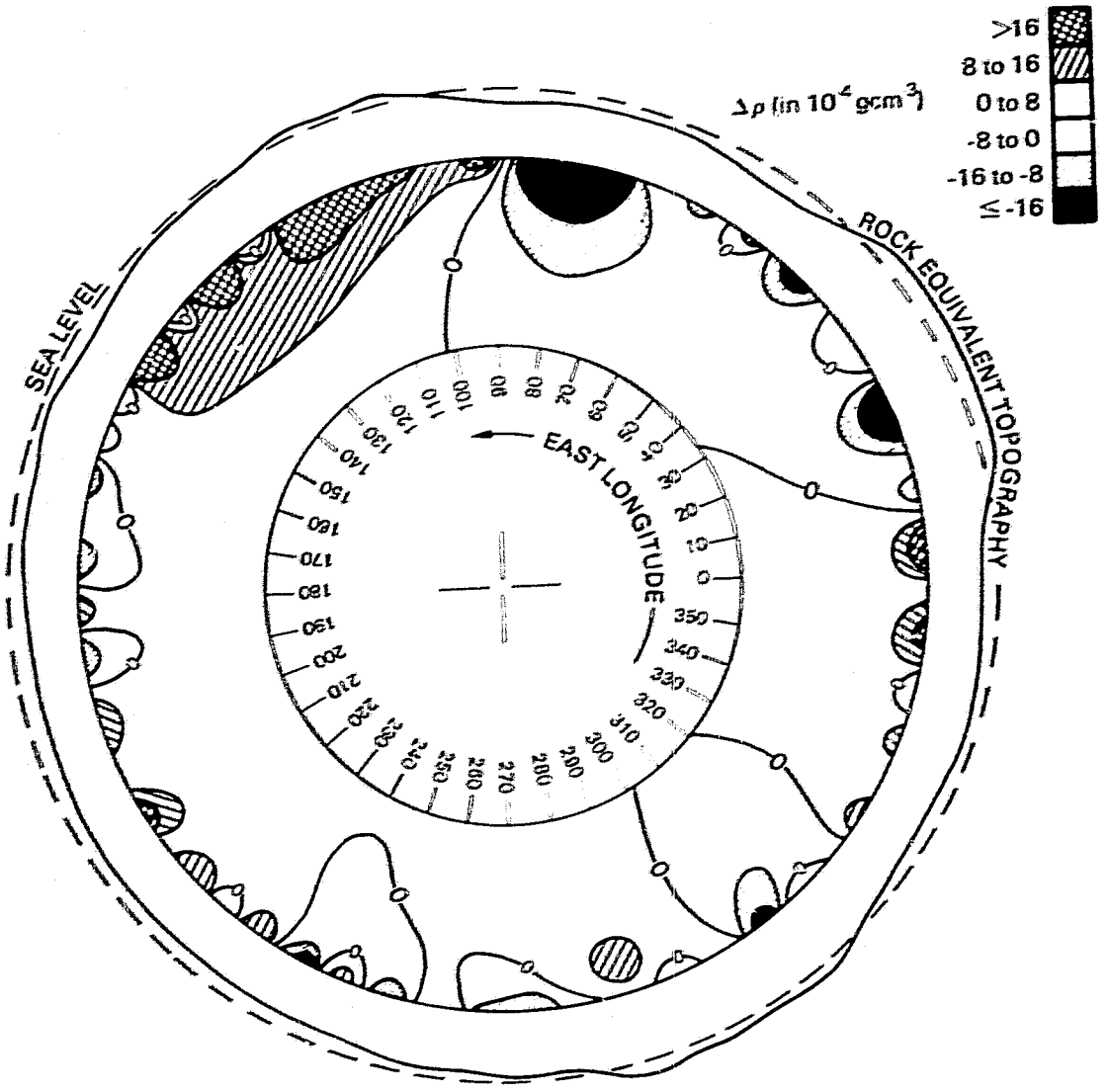

Figure 2. Lateral density variation $\Delta\rho_I$ in the equatorial plane of the earth for the case of 30 km of compensated crust removed. Sea level is displaced from the earth's surface for clarity, and the rock-equivalent topography is greatly exaggerated. Anomalies in the core are not shown.

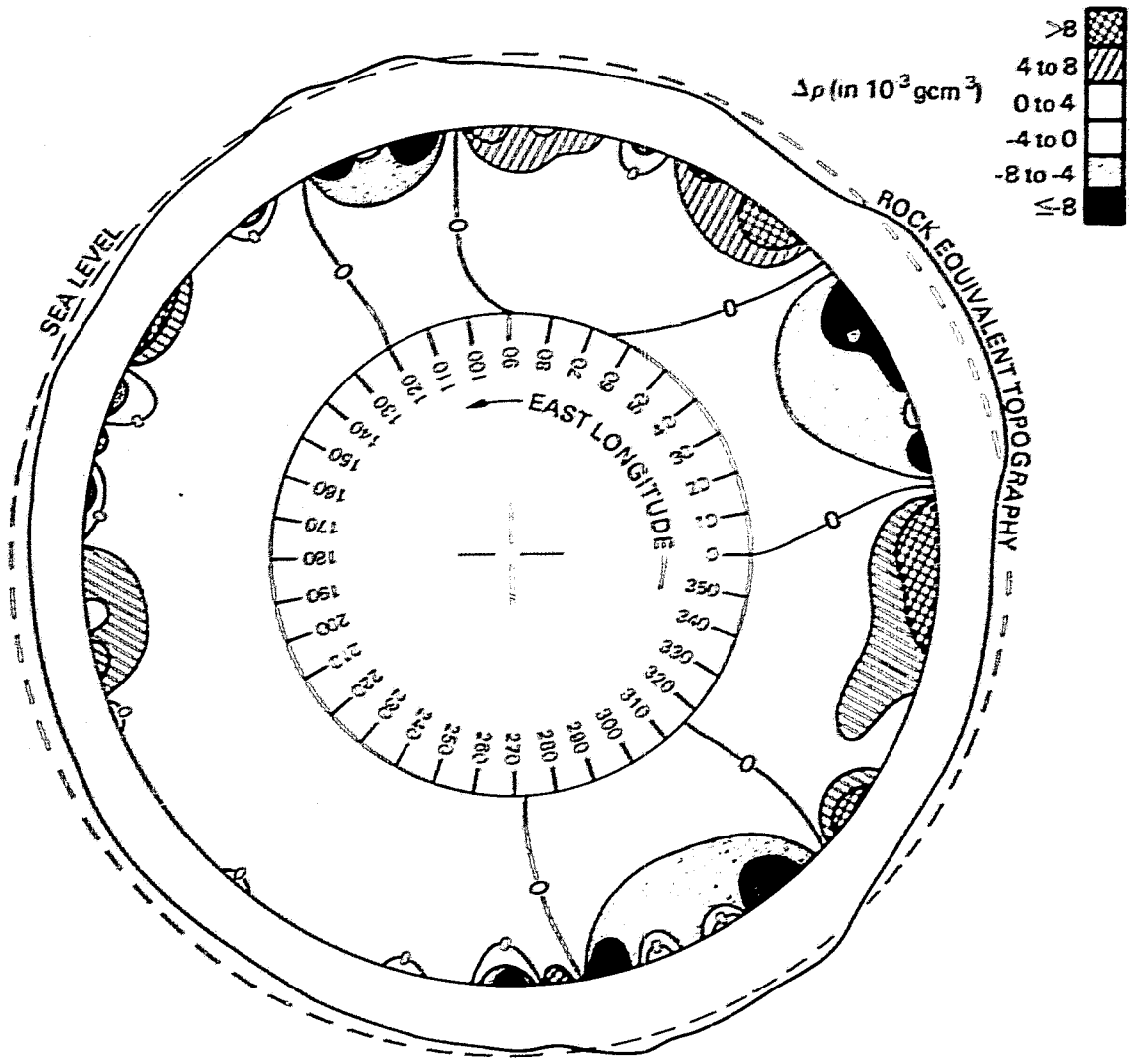

Figure 3. Lateral density variation $\Delta\rho_I$ in the equatorial plane of the earth for the case of 30 km of uncompensated crust removed. Sea level is displaced from the earth's surface for clarity, and the rock-equivalent topography is greatly exaggerated. Anomalies in the core are not shown.

FIGURE CAPTIONS

Plate 1. Lateral density variation $\Delta\rho_l$ at 3 km depth (no crust removed). Note that no zero line is shown, which would make the map too busy.

Plate 2. Lateral density variation $\Delta\rho_l$ at 30 km depth for 30 km of uncompensated crust removed. Note that no zero line is shown, which would make the map too busy.

Figure 1. Lateral density variation $\Delta\rho_l$ in the equatorial plane of the earth for the case of no crust removed. Sea level is displaced from the earth's surface for clarity, and the rock-equivalent topography is greatly exaggerated. Anomalies in the core are not shown.

Figure 2. Lateral density variation $\Delta\rho_l$ in the equatorial plane of the earth for the case of 30 km of compensated crust removed. Sea level is displaced from the earth's surface for clarity, and the rock-equivalent topography is greatly exaggerated. Anomalies in the core are not shown.

Figure 3. Lateral density variation $\Delta\rho_l$ in the equatorial plane of the earth for the case of 30 km of uncompensated crust removed. Sea level is displaced from the earth's surface for clarity, and the rock-equivalent topography is greatly exaggerated. Anomalies in the core are not shown.

Table 1

The Coefficients δ_ℓ for No Crust Removed ($R_U = 1$) and 30 km of Crust Removed ($R_U = 6341/6371$).

Degree ℓ	δ_ℓ	
	$R_U = 1$	$R_U = 6341/6371$
1	1.096	1.112
2	2.794	2.857
3	5.285	5.445
4	8.580	8.911
5	12.701	13.295
6	17.659	18.635
7	23.467	24.965
8	30.130	32.316
9	37.653	40.715
10	46.036	50.191
11	55.283	60.771
12	65.392	72.479
13	76.367	85.344
14	88.207	99.393
15	100.913	114.653
16	114.486	131.152
17	128.929	148.920
18	144.241	167.987
19	160.426	188.382
20	177.485	210.138
21	195.421	233.286
22	214.235	257.858
23	233.931	283.890
24	254.510	311.414
25	275.976	340.466
26	298.332	371.082
27	321.579	403.298
28	345.722	437.152
29	370.763	472.681
30	396.706	509.925
31	423.552	548.922
32	451.306	589.713
33	479.971	632.339
34	509.548	676.842
35	540.043	723.263
36	571.458	771.647

APPENDIX

Finding the variance $\sigma_n^2 = \langle n_j^2 \rangle - \langle n_j \rangle^2$ from (8) closely follows the standard statistical mechanics treatment (e.g., Reif, 1965, pp. 336-337). It is given by

$$\sigma_n^2 = \frac{\partial^2 \ln Z}{\partial \left(\alpha_1 f_1 (\vec{r}_j)\right)^2}$$

which gives

$$\frac{\sigma_n}{\langle n_j \rangle} = \sqrt{1 + \frac{1}{\langle n_j \rangle}} = \frac{\sigma_\rho}{\rho(\vec{r})}, \quad \sigma_\rho = \frac{m}{dv} \sigma_n$$

for particles following Bose-Einstein statistics (Reif, 1965, p. 346; Morse, 1969, p. 333). Because it is assumed that $\langle n_j \rangle << 1$, all that can be said about σ_ρ is that $\sigma_\rho > \rho(\vec{r})$, since no commitment to the value of $\langle n_j \rangle$ has been made. Hence the data do not greatly constrain the density distribution.

APPENDIX B

The computer program used to generate the plates and figures is listed here. Plates 1 and 2 use subroutine VANDER. Figures 1, 2, and 3 use subroutine SLICE.

```
C
C
C        *INFORMATION THEORY DENSITY DISTRIBUTION*                          MAI    1
C
C
C     THIS PROGRAM COMPUTES THE INFORMATION THEORY DENSITY DISTRIBUTION MAI    2
C BASED ON THE GRAVITY FIELD. IT ASSUMES MAXWELL-BOLTZMANN STATISTICS   MAI    3
C AND THAT THE SPHERICALLY SYMMETRIC PART OF THE DENSITY DISTRIBUTION   MAI    4
C IS KNOWN.                                                             MAI    5
C
C     THE PROGRAM USES SPHERICAL HARMONICS. THE LATERAL DENSITY         MAI    6
C VARIATION IS ASSUMED TO BE A SMALL PERTURBATION ON TOP OF THE         MAI    7
C SPHERICALLY SYMMETRIC DENSITY DISTRIBUTION.                           MAI    8
C
C     THE PROGRAM COMPUTES THE DENSITY VARIATION, RELATIVE DENSITY, OR  MAI    9
C ACTUAL DENSITY INSIDE THE EARTH, WHICH MAY BE DISPLAYED IN VARIOUS     MAI   10
C WAYS ACCORDING TO A CHOSEN SUBROUTINE. THE DISPLAY IS IN ONE OF TWO   MAI   11
C MODES: PRINT-OUT PICTURES OR DICOMED PHOTOGRAPHS.                     MAI   12
C
C     THE DENSITY IS DEFINED AS THE SPHERICALLY SYMMETRIC PART          MAI   13
C (RHO SUB-ZERO) PLUS THE DENSITY VARIATION (DELTA RHO). THE RELATIVE    MAI   14
C DENSITY IS DEFINED AS DELTA RHO DIVIDED BY RHO SUB-ZERO.              MAI   15
C
C     CRUSTAL MODELS (SUCH AS AN ISOSTATICALLY COMPENSATED CRUST OR     MAI   16
C AN ISOSTATICALLY UNCOMPENSATED CRUST) MAY BE SUBTRACTED OFF IF        MAI   17
C DESIRED AND THE INFORMATION THEORY ALGORITHM APPLIED TO THE REMAINING MAI   18
C GRAVITY SIGNAL.                                                       MAI   19
C
C     ALSO, THE DEGREES USED BY THE SPHERICAL HARMONIC FIELDS CAN BE    MAI   20
C RESTRICTED TO A CERTAIN RANGE (BETWEEN LMIN AND LMAX INCLUSIVE) IF    MAI   21
C SO DESIRED.                                                           MAI   22
C
C
C
C        NOTATION                                                           MAI   23
C
C
C       GENERAL DATA                                                       MAI   24
C
C     PI     = 3.1415926535897900                                        MAI   25
C     PIDIV2 = PI/2.000                                                  MAI   26
C     PI2    = 2.000*PI                                                  MAI   27
C     LLOW   = MINIMUM DEGREE OF GRAVITY/TOPOGRAPHY/CRUSTAL FIELD        MAI   28
C              RECORDS READ                                              MAI   29
C     LUP    = MAXIMUM DEGREE OF GRAVITY/TOPOGRAPHY/CRUSTAL FIELD        MAI   30
C              RECORDS READ                                              MAI   31
C     LMIN   = MINIMUM DEGREE OF GRAVITY/TOPOGRAPHY/CRUSTAL FIELD        MAI   32
C              TO BE USED IN PROGRAM                                     MAI   33
C     LMAX   = MAXIMUM DEGREE OF GRAVITY/TOPOGRAPHY/CRUSTAL FIELD        MAI   34
C              TO BE USED IN PROGRAM                                     MAI   35
C     SUBNME = NAME OF SUBROUTINE CALLED                                 MAI   36
C     COMENT = GENERAL COMMENTS ABOUT PARTICULAR RUN (SUCH AS THE NAME   MAI   37
C              OF THE REGION BEING EXAMINED, ETC)                        MAI   38
C     NPRINT = 1 IF GRAVITY/TOPOGRAPHY/CRUSTAL FIELD COEFFICIENTS ARE    MAI   39
C              TO BE LISTED, =0 IF NOT                                   MAI   40
C
C       EARTH DATA                                                         MAI   41
C
C     RHOAVG = AVERAGE DENSITY OF THE EARTH IN GRAMS/CM**3               MAI   42
C     RADAVG = AVERAGE RADIUS OF EARTH IN KILOMETERS                     MAI   43
C     RCORKM = RADIUS OF OUTER CORE IN KILOMETERS                        MAI   44
C     RCORE  = RCORKM/RADAVG                                             MAI   45
C     RLOWKM = LOWER RADIAL LIMIT ALLOWED FOR DENSITY ANOMALIES, IN      MAI   46
C              KILOMETERS                                                MAI   47
C     RLOWER = RLOWKM/RADAVG                                             MAI   48
C     RUPKM  = UPPER RADIAL LIMIT ALLOWED FOR DENSITY ANOMALIES, IN      MAI   49
C              KILOMETERS                                                MAI   50
C     RUPPER = RUPKM/RADAVG                                              MAI   51
C
C       GRAVITY FIELD                                                      MAI   52
C
C     GRAV   = DESCRIPTION OF GRAVITY FIELD                              MAI   53
C
C       CRUST                                                              MAI   54
C
C     CCRUST = DESCRIPTION OF CRUSTAL MODEL                              MAI   55
C     NCRUST = 1 IF CRUSTAL MODEL FIELD IS SUBTRACTED FROM GRAVITY       MAI   56
C              FIELD, =0 IF NOT                                          MAI   57
C
C       TOPOGRAPHY                                                         MAI   58
C
C     TTOPO  = DESCRIPTION OF TOPOGRAPHY                                 MAI   59
C     TOPO   = ARRAY IN WHICH TOPOGRAPHY COEFFICIENTS ARE STORED         MAI   60
C
C       LATERAL DENSITY DISTRIBUTION                                       MAI   61
C
C     COMMNT = REMARKS ABOUT THE COE(L) (SUCH AS THE DEPTHS FOR WHICH    MAI   62
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C              THEY WERE COMPUTED)                                          MAI   63
C     CCE    = INFORMATION-THEORETIC COEFFICIENTS BASED ON THE             MAI   64
C              SPHERICALLY SYMMETRIC DENSITY DISTRIBUTION                   MAI   65
C     CLM    = INFORMATION-THEORETIC RELATIVE DENSITY/DENSITY/DENSITY      MAI   66
C              VARIATION SPHERICAL HARMONIC COEFFICIENTS                    MAI   67
C     NDEN   = 0 IF RELATIVE DENSITY DISTRIBUTION IS PLOTTED, =1 IF        MAI   68
C              ACTUAL DENSITY IS PLOTTED, =2 IF DENSITY VARIATION IS        MAI   69
C              PLOTTED                                                      MAI   70
C     REFDEN = REFERENCE DENSITY, USED ONLY IF NDEN=1                      MAI   71
C
C       PICTURE DATA                                                       MAI   72
C
C     NPHOTO = 0 IF PRINT-OUT PICTURE IS DESIRED, =1 IF DICOMED            MAI   73
C              PHOTOGRAPH IS DESIRED                                       MAI   74
C     MAXSYM = NUMBER OF ALPHANUMERIC SYMBOLS USED FOR PRINT-OUT           MAI   75
C              PICTURE OR DICOMED PHOTO                                    MAI   76
C     ALPHA  = ARRAY IN WHICH ALPHANUMERIC SYMBOLS USED FOR PRINT-OUT      MAI   77
C              PICTURES ARE STORED, IN ORDER FROM LOW TO HIGH              MAI   78
C              RELATIVE DENSITY/DENSITY/DENSITY VARIATION                  MAI   79
C     BETA   = ARRAY IN WHICH DICOMED COLOR CODING NUMBERS ARE             MAI   80
C              STORED, USED FOR DICOMED PHOTO, IN ORDER FROM LOW           MAI   81
C              TO HIGH RELATIVE DENSITY/DENSITY/DENSITY VARIATION          MAI   82
C     SCALE  = RELATIVE DENSITY/DENSITY/DENSITY VARIATION INTERVAL         MAI   83
C              BETWEEN ALPHANUMERIC SYMBOLS (OR COLORS)                    MAI   84
C              (UNITS: NONE IF NDEN=0, GRAMS/CM**3 IF NDEN=1OR 2)          MAI   85
C
C
C     SUBROUTINES CALLED:                                                  MAI   86
C
C      1. CUTS   (IF SUBNME .EQ. CUT)                                      MAI   87
C      2. PIECE  (IF SUBNME .EQ. PIE)                                      MAI   88
C      3. POLES  (IF SUBNME .EQ. POL)                                      MAI   89
C      4. SECTNS (IF SUBNME .EQ. SEC)                                      MAI   90
C      5. SLICE  (IF SUBNME .EQ. SLI)                                      MAI   91
C      6. VANDER (IF SUBNME .EQ. VAN)                                      MAI   92
C
C
C     NOTES                                                                MAI   93
C
C      1. ALL SPHERICAL HARMONIC FIELDS (GRAVITY, TOPOGRAPHIC, CRUSTAL)    MAI   94
C         USE KAULA'S 4PI NORMALIZATION.                                   MAI   95
C      2. THE TOPOGRAPHIC FIELD IS NORMALIZED TO THE RADIUS OF THE         MAI   96
C         EARTH (IN KILOMETERS).                                           MAI   97
C      3. THE FOLLOWING CONDITIONS MUST BE SATISFIED:                      MAI   98
C         LMIN .GE. LLOW                                                   MAI   99
C         LMAX .LE. LUP .                                                  MAI  100
C      4. THE DENSITY VARIATION OR RELATIVE DENSITY IS MORE CONVENIENT     MAI  101
C         TO DISPLAY THAN THE ACTUAL DENSITY.                              MAI  102
C      5. IF WE HAVE ALPHA(JNUM) WHERE JNUM .GT. MAXSYM, THEN THE          MAI  103
C         PROGRAM SETS JNUM=MAXSYM. ALSO, IF JNUM .LT. 1, THEN WE SET      MAI  104
C         JNUM=1. LIKEWISE FOR BETA(JNUM).                                 MAI  105
C         IN OTHER WORDS, IF THE RELATIVE DENSITY/DENSITY/DENSITY          MAI  106
C         VARIATION GOES OFF SCALE AT EITHER END, THEN THE LIMIT AT        MAI  107
C         THAT END IS USED.                                                MAI  108
C      6. PROGRAM NORMALIZES ALL RADIAL DISTANCES BY DIVIDING RADIAL       MAI  109
C         DISTANCE (IN KILOMETERS) BY RADAVG.                              MAI  110
C
C
C
C     SAMPLE INPUT DATA   (COLUMN 1 OF INPUT STARTS IN COLUMN 3 HERE)      MAI  111
C
C  LLOW  LUP                                  (FORMAT: 4I5)                MAI  112
C    36   36                                                               MAI  113
C
C  LMIN LMAX                                  (FORMAT: 4I5)                MAI  114
C    36   36                                                               MAI  115
C
C NCRUST NPRINT                               (FORMAT: 4I5)                MAI  116
C     1    1                                                               MAI  117
C
C RADAVG    RCORKM    RHCAVG                  (FORMAT: 8F10.5)             MAI  118
C 6371.0    3485.7     5.517                                               MAI  119
C
C                (COMMNT(J), J=1,14)         (FORMAT: 13A6,A2)            MAI  120
C DENSITY COEFFICIENTS COE(L) (RANGE: 670 TO 30 KM DEPTH)                   MAI  121
C
C RLOWKM     RUPKM                            (FORMAT: 8F10.5)             MAI  122
C 5701.0    6341.0                                                        MAI  123
C
C     K    COE(K)                            (FORMAT: I5,F20.4)           MAI  124
C     1  3.4505062                                                        MAI  125
C     2  6.4100380                                                        MAI  126
C    ...                                                                  MAI  127
C    35  723.66557                                                        MAI  128
C    36  771.99419                                                        MAI  129
C
C                    (GRAV(J), J=1,14)      (FORMAT: 13A6,A2)            MAI  130
```

```
C GEM10B, USING NAKIBOGLU(1975) HYDROSTATIC FOR L=2,4; M=0                MAI  131
C
C        L M        C                  S           (FORMAT: 6X,2I2,2D15.8)  MAI  132
C        1 0 0.0                0.0                                        MAI  133
C        1 1 0.0                0.0                                        MAI  134
C                                ...                                       MAI  135
C       3635 0.359901570-C8-0.731970240-08                                 MAI  136
C       3636 0.249368180-C8-0.886649470-09                                 MAI  137
C
C                          (TTOPO(J), J=1,14)    (FORMAT: 13A6,A2)         MAI  138
C ROCK-EQUIVALENT TOPCGRAPHY - NORMALIZED TO RADIUS OF THE EARTH           MAI  139
C
C        L M        C                  S           (FORMAT: 6X,2I2,2D15.8)  MAI  140
C RECCEF 1 0 C.731720180-C4 0.0                                            MAI  141
C RECOEF 1 1 C.63249042C-C4 0.422260593C-04                                MAI  142
C                                ...                                       MAI  143
C RECOEF3635 0.145268950-C5-0.776859170-06                                 MAI  144
C RECOEF3636 0.723308860-C6-0.240208980-06                                 MAI  145
C
C                          (CCRUST(J), J=1,14)   (FORMAT: 13A6,A2)         MAI  146
C GRAVITY COEFFICIENTS-UNCOMPENSATED CRUST,FROM KAULAGLEE,SCRIPPS,NAVY     MAI  147
C
C    L   M        C                  S           (FORMAT: 2I4,1P2D15.6)   MAI  148
C    1   C    3.4352110-C4    0.0                                           MAI  149
C    1   1    2.9878850-C4    2.0724950-C4                                  MAI  150
C                                ...                                       MAI  151
C   36  35    3.5216880-C7   -2.2664080-C7                                 MAI  152
C   36  36    5.4404990-C8   -1.1692660-C7                                 MAI  153
C
C NPHOTO MAXSYM SCALE                          (FORMAT: 2I5,F10.5)         MAI  154
C     0   20   0.001                                                       MAI  155
C
C  (ALPHA(J), J=1,21)                          (FORMAT: 21A1)              MAI  156
C JIHGFEDCBA1234567891                                                     MAI  157
C
C         (BETA(J), J=1,11)                    (FORMAT: 11I3)              MAI  158
C   7   8   9 10 31 20 19 18 17 22  1                                      MAI  159
C
C   NDEN   REFDEN                              (FORMAT: I5,F20.9)          MAI  160
C     0      0.0                                                           MAI  161
C     ...                                                                  MAI  162
C     (FOR THE REST OF THE SAMPLE INPUT, WHICH RELATES TO THE              MAI  163
C PARTICULAR SUBROUTINE CALLED, SEE THE SUBROUTINE.)                       MAI  164
C
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                             MAI  165
      INTEGER*2 BETA(11)                                                   MAI  166
      DIMENSION ALPHA(23),LCWHI(205,2)                                     MAI  167
      DIMENSION COMENT (14)                                                MAI  168
      DIMENSION CLP(36,37,2),COE(36)                                       MAI  169
      DIMENSION TOPO(36,37,2)                                              MAI  170
      DIMENSION COMMNT(14),GRAV(14),CCRUST(14),TTOPO(14)                   MAI  171
      COMMCN/BLKB/CLP,CCE                                                  MAI  172
      COMMCN/BLKC/F,PI,PI2,PIDIV2,SCALE,NPHOTO,MAXSYM                      MAI  173
      COMMCN/BLKD/ALPHA,LCWHI                                              MAI  174
      COMMCN/BLKG/LMIN,LMAX,LLOW,LUP                                       MAI  175
      COMMCN/BLKH/RADAVG,RCORE,RLOWER,RUPPER                               MAI  176
      COMMCN/BLKI/COMENT                                                   MAI  177
      COMMCN/BLKJ/NDEN,REFDEN                                              MAI  178
      COMMCN/BLKK/TOPO                                                     MAI  179
      COMMCN/BLKT/BETA                                                     MAI  180
      DATA POL,PIE/6HPOLES ,6HPIECE /                                      MAI  181
      DATA SLI,SEC,VAN/6HSLICE ,6HSECTNS,6HVANDER/                         MAI  182
      DATA CUT/6HCUTS  /                                                   MAI  183
      DATA BLANK,DOLLAR/1H ,1H$/                                           MAI  184
C
C   SUPPRESS UNDERFLOW ERROR MESSAGES ON SUBROUTINE LGENDR                 MAI  185
      CALL ERRSET(208,256,-1,1)                                            MAI  186
C
C   INITIALIZE BASIC CONSTANTS                                             MAI  187
      PI=3.14159265358979C0                                                MAI  188
      F=PI/180.0D0                                                         MAI  189
      PI2=2.0C0*PI                                                         MAI  190
      PIDIV2=PI/2.0D0                                                      MAI  191
      ALPHA(22)=DOLLAR                                                     MAI  192
      ALPHA(23)=BLANK                                                      MAI  193
C
C   READ IN BASIC DATA                                                     MAI  194
      READ (5,17) LLOW,LUP                                                 MAI  195
 17   FORMAT (4I5)                                                         MAI  196
      READ (5,17) LMIN,LMAX                                                MAI  197
      READ (5,17) NCRUST,NPRINT                                            MAI  198
C
      READ (5,104) RADAVG,RCORKM,RHOAVG                                    MAI  199
      RCORE=RCORKM/RADAVG                                                  MAI  200
C
C   SET DATA ARRAYS INITIALLY EQUAL TO ZERO                                MAI  201
```

```
      MMAX=LMAX + 1                                                     MAI  202
      DO 23 L=1,LMAX                                                    MAI  203
      CCE(L)=0.000                                                      MAI  204
      DO 23 M=1,MMAX                                                    MAI  205
      TCPC(L,M,1)=0.000                                                 MAI  206
      TCPC(L,M,2)=0.000                                                 MAI  207
      CLM(L,M,1)=0.000                                                  MAI  208
   23 CLM(L,M,2)=0.000                                                  MAI  209
C
C   READ IN CCE(L) DATA                                                 MAI  210
      READ (5,25) (COMMNT(J), J=1,14)                                   MAI  211
   25 FORMAT (13A6,A2)                                                  MAI  212
C
      READ (5,104) RLOWKM,RUPKM                                         MAI  213
  104 FORMAT (8F10.5)                                                   MAI  214
      RLOWER=RLOWKM/RADAVG                                              MAI  215
      RUPPER=RUPKM/RADAVG                                               MAI  216
C
      ICOUNT=0                                                          MAI  217
      DO 24 L=LMIN,LMAX                                                 MAI  218
      READ(5,21) K,CCE(K)                                               MAI  219
   21 FORMAT (I5,F20.9)                                                 MAI  220
      ICOUNT=ICOUNT + 1                                                 MAI  221
   24 CONTINUE                                                          MAI  222
C
C   READ IN GRAVITY FIELD C'S AND S'S                                   MAI  223
C
      READ (5,25) (GRAV(J), J=1,14)                                     MAI  224
      WRITE (6,14)                                                      MAI  225
      WRITE (6,32)                                                      MAI  226
   32 FORMAT (20X,'GRAVITY FIELD COEFFICIENTS',/)                       MAI  227
      WRITE (6,33) (GRAV(J), J=1,14)                                    MAI  228
   33 FORMAT (20X,13A6,A2,///)                                          MAI  229
      WRITE (6,34)                                                      MAI  230
   34 FORMAT (10X,' L',2X,' M',9X,'C',10X,'S',/)                        MAI  231
      JCOUNT=0                                                          MAI  232
    2 READ (5,1,END=3) L,M,C,S                                          MAI  233
    1 FORMAT (6X,2I2,2D15.8)                                            MAI  234
      IF (NPRINT .EQ. 0) GO TO 331                                      MAI  235
C   WRITE GRAVITY FIELD C'S AND S'S                                     MAI  236
      WRITE (6,35) L,M,C,S                                              MAI  237
   35 FORMAT (10X,I2,2X,I2,2X,D15.8,2X,D15.8)                           MAI  238
  331 JCOUNT=JCOUNT + 1                                                 MAI  239
      IF (L .GT. LMAX) GO TO 13                                         MAI  240
      IF (L .LT. LMIN) GO TO 13                                         MAI  241
C   COMPUTE DENSITY DISTRIBUTION COEFFICIENTS                           MAI  242
      CCEFF=RHOAVG*(CCE(L))                                             MAI  243
      M1= M + 1                                                         MAI  244
      CLM(L,M1,1)=C*CCEFF                                               MAI  245
      CLM(L,M1,2)=S*CCEFF                                               MAI  246
      IF (L .EQ. LUP .AND. M .EQ. LUP) GO TO 3                          MAI  247
   13 CONTINUE                                                          MAI  248
      GO TO 2                                                           MAI  249
    3 CONTINUE                                                          MAI  250
      WRITE (6,120) JCOUNT                                              MAI  251
  120 FORMAT (/,10X,'NUMBER OF GRAVITY FIELD RECORDS READ:',1X,I10)     MAI  252
C
C   READ IN TOPOGRAPHIC C'S AND S'S                                     MAI  253
C
      READ (5,25) (TTOPO(J), J=1,14)                                    MAI  254
      WRITE (6,14)                                                      MAI  255
      WRITE (6,321)                                                     MAI  256
  321 FORMAT (20X,'TOPOGRAPHY COEFFICIENTS',/)                          MAI  257
      WRITE (6,33) (TTOPO(J), J=1,14)                                   MAI  258
      WRITE (6,34)                                                      MAI  259
      LCOUNT=0                                                          MAI  260
  322 READ (5,1,END=324) L,M,C,S                                        MAI  261
      IF (NPRINT .EQ. 0) GO TO 332                                      MAI  262
C   WRITE TOPOGRAPHIC C'S AND S'S                                       MAI  263
      WRITE (6,35) L,M,C,S                                              MAI  264
  332 LCOUNT=LCOUNT + 1                                                 MAI  265
      IF (L .GT. LMAX) GO TO 323                                        MAI  266
      IF (L .LT. LMIN) GO TO 323                                        MAI  267
      M1=M + 1                                                          MAI  268
      TCPC(L,M1,1)=C                                                    MAI  269
      TCPC(L,M1,2)=S                                                    MAI  270
      IF (L .EQ. LUP .AND. M .EQ.  9) GO TO 324                         MAI  271
  323 CONTINUE                                                          MAI  272
      GO TO 322                                                         MAI  273
  324 CONTINUE                                                          MAI  274
      WRITE (6,125) LCOUNT                                              MAI  275
  125 FORMAT (/,10X,'NUMBER OF TOPOGRAPHY RECORDS READ:',3X,I10)        MAI  276
C
      IF (NCRUST .EQ. 0) KCOUNT=0                                       MAI  277
      IF (NCRUST .EQ. 0) GO TO 43                                       MAI  278
C
C   READ IN CRUSTAL C'S AND S'S                                         MAI  279
C
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      READ (5,25) (CCRUST(J), J=1,14)                                    MAI  280
      WRITE (6,14)                                                       MAI  281
      WRITE (6,26) (CCRUST(J), J=1,14)                                   MAI  282
      KCOUNT=0                                                           MAI  283
      WRITE (6,34)                                                       MAI  284
   41 READ (5,42,END=43) L,M,C,S                                         MAI  285
   42 FORMAT (2I4,1P2D15.8)                                              MAI  286
      IF (NPRINT .EQ. 0) GO TO 333                                       MAI  287
C     WRITE OUT CRUSTAL C'S AND S'S                                      MAI  288
      WRITE (6,35) L,M,C,S                                               MAI  289
  333 KCOUNT=KCOUNT + 1                                                  MAI  290
      IF (L .GT. LMAX) GO TO 52                                          MAI  291
      IF (L .LT. LMIN) GO TO 52                                          MAI  292
      CCOEFF=RHOAVG*(CCOE(L))                                            MAI  293
      M1=M + 1                                                           MAI  294
C     SUBTRACT CRUSTAL FIELD FROM DENSITY COEFFICIENTS                   MAI  295
      CLM(L,M1,1)=CLM(L,M1,1) - C*CCOEFF                                 MAI  296
      CLM(L,M1,2)=CLM(L,M1,2) - S*CCOEFF                                 MAI  297
      IF (L .EQ. LUP .AND. M .EQ. LUP) GO TO 43                          MAI  298
   52 CONTINUE                                                           MAI  299
      GO TO 41                                                           MAI  300
   43 CONTINUE                                                           MAI  301
      WRITE (6,121) KCOUNT                                               MAI  302
  121 FORMAT (/,10X,'NUMBER OF CRUSTAL FIELD RECORDS READ:',1X,I10)      MAI  303
C
C     READ IN DISPLAY DATA                                               MAI  304
      READ (5,201) NPHOTO,MAXSYM,SCALE                                   MAI  305
  201 FORMAT (2I5,7F10.5)                                                MAI  306
      READ (5,50) (ALPHA(J), J=1,21)                                     MAI  307
   50 FORMAT (21A1)                                                      MAI  308
      READ (5,51) (BETA(J),J=1,11)                                       MAI  309
   51 FORMAT(11I3)                                                       MAI  310
      READ (5,21) NDEN,REFDEN                                            MAI  311
C
C     WRITE OUT INPUT DATA                                               MAI  312
C
      WRITE (6,14)                                                       MAI  313
      WRITE (6,300)                                                      MAI  314
  300 FORMAT (20X,'INFORMATION THEORY DENSITY DISTRIBUTION',///,20X,     MAI  315
     . 'BASED ON THE GRAVITY FIELD COEFFICIENTS',/,20X,                  MAI  316
     . 'AND KNOWN SPHERICALLY SYMMETRIC DENSITY DISTRIBUTION',/////)     MAI  317
      WRITE (6,340) LLOW                                                 MAI  318
  340 FORMAT (10X,'LLOW=',I4,30X,'(MINIMUM DEGREE OF SPHERICAL HARMONIC MAI  319
     .FIELDS)',/)                                                        MAI  320
      WRITE (6,341) LUP                                                  MAI  321
  341 FORMAT (10X,'LUP =',I4,30X,'(MAXIMUM DEGREE OF SPHERICAL HARMONIC MAI  322
     .FIELDS)',///)                                                      MAI  323
      WRITE (6,342) LMIN                                                 MAI  324
  342 FORMAT (10X,'LMIN=',I4,30X,'(MINIMUM DEGREE USED IN RUN)',/)       MAI  325
      WRITE (6,343) LMAX                                                 MAI  326
  343 FORMAT (10X,'LMAX=',I4,30X,'(MAXIMUM DEGREE USED IN RUN)',//)      MAI  327
      WRITE (6,303) NCRUST                                               MAI  328
  303 FORMAT (10X,'NCRUST=',I3,29X,'(=1 IF CRUSTAL MODEL IS SUBTRACTED; MAI  329
     .=0 IF NOT)',//)                                                    MAI  330
      WRITE (6,330) NPRINT                                               MAI  331
  330 FORMAT (10X,'NPRINT=',I3,29X,'(=1 IF GRAVITY, TOPOGRAPHIC, AND CRUMAI  332
     .STAL COEFFICIENTS ARE PRINTED; =0 IF NOT)',//)                     MAI  333
      WRITE (6,304) RADAVG                                               MAI  334
  304 FORMAT (10X,'RADAVG=',1X,F10.3,1X,'KM',18X,'(AVERAGE RADIUS OF EARMAI  335
     .TH)',///)                                                          MAI  336
      WRITE (6,305) RCORKM                                               MAI  337
  305 FORMAT (10X,'RCORKM=',1X,F10.3,1X,'KM',18X,'(RADIUS OF CORE)',///) MAI  338
      WRITE (6,306) RHOAVG                                               MAI  339
  306 FORMAT (10X,'RHOAVG=',1X,F10.5,1X,'GRAM/CM**3',10X,'(AVERAGE DENSIMAI  340
     .TY OF EARTH)',///)                                                 MAI  341
      WRITE (6,307) RLOWKM                                               MAI  342
  307 FORMAT (10X,'RLOWKM=',1X,F10.3,1X,'KM',18X,'(LOWER BOUND ON ANOMALMAI  343
     .IES)',///)                                                         MAI  344
      WRITE (6,308) RUPKM                                                MAI  345
  308 FORMAT (10X,'RUPKM=',2X,F10.3,1X,'KM',18X,'(UPPER BOUND ON ANOMALIMAI  346
     .ES)',///)                                                          MAI  347
      WRITE (6,309) NPHOTO                                               MAI  348
  309 FORMAT (10X,'NPHOTO=',I3,29X,'(=1 IF PHOTO IS TAKEN; =0 FOR PRINT-MAI  349
     .OUT PICTURE)',///)                                                 MAI  350
      WRITE (6,311) SCALE                                                MAI  351
  311 FORMAT (10X,'SCALE=',1X,F10.5,22X,'(UNITS: NONE IF NDEN=0, GRAM/CMMAI  352
     .**3 IF NDEN=1 OR 2)',///)                                          MAI  353
      WRITE (6,310) MAXSYM                                               MAI  354
  310 FORMAT (10X,'MAXSYM=',I5,27X,'(NUMBER OF ALPHANUMERIC SYMBOLS USEDMAI  355
     .)',///)                                                            MAI  356
      WRITE (6,312) (ALPHA(J), J=1,21)                                   MAI  357
  312 FORMAT (10X,'ALPHA(J):',1X,21A1, 8X,'(FROM LOW TO HIGH CENSITY)',/MAI  358
     ./)                                                                 MAI  359
      WRITE (6,313) (BETA(J), J=1,11)                                    MAI  360
  313 FORMAT (10X,'BETA(J):',1X,11(I3,1X),10X,'(USED FOR PHOTO)',///)    MAI  361
      WRITE (6,314) NDEN                                                 MAI  362
  314 FORMAT (10X,'NDEN=',I3,31X,'(=0 FOR RELATIVE DENSITY, =1 FOR ACTUAMAI  363
     .L DENSITY, =2 FOR DENSITY VARIATION)',///)                         MAI  364
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```
      WRITE (6,317) REFDEN                                                  MAI  365
  317 FORMAT (10X,'REFDEN=',1X,F10.7,1X,'GRAM/CM**3',10X,'(REFERENCE DEN   MAI  366
     .SITY, USED WHEN NDEN=1)',//)                                          MAI  367
      WRITE (6,326)                                                         MAI  368
  326 FORMAT (//,10X)                                                       MAI  369
      WRITE (6,315) (GRAV(J), J=1,14)                                       MAI  370
  315 FORMAT (10X,'GRAVITY FIELD:',1X,13A6,A2)                              MAI  371
      WRITE (6,120) JCOUNT                                                  MAI  372
      WRITE (6,325) (TTOPO(J), J=1,14)                                      MAI  373
  325 FORMAT (//,10X,'TOPOGRAPHY',3X,':',1X,13A6,A2)                        MAI  374
      WRITE (6,125) LCOUNT                                                  MAI  375
      IF (NCRUST .EQ. 0) GO TO 318                                          MAI  376
      WRITE (6,316) (CCRUST(J), J=1,14)                                     MAI  377
  316 FORMAT (//,10X,'CRUST',6X,':',1X,13A6,A2)                             MAI  378
      WRITE (6,121) KCOUNT                                                  MAI  379
      GO TO 319                                                             MAI  380
  318 WRITE (6,320)                                                         MAI  381
  320 FORMAT (//,10X,'CRUST',6X,':',1X,'NO CRUSTAL MODEL SUBTRACTED OUT'    MAI  382
     .)                                                                     MAI  383
  319 CONTINUE                                                              MAI  384
C
C   WRITE OUT COE(L)                                                        MAI  385
      WRITE (6,14)                                                          MAI  386
   14 FORMAT (1H1)                                                          MAI  387
      WRITE (6,26) (COMMNT(J), J=1,14)                                      MAI  388
   26 FORMAT (10X,13A6,A2,//)                                               MAI  389
C
      WRITE (6,29)                                                          MAI  390
   29 FORMAT (24X,'L',2CX,'COE(L)',/)                                       MAI  391
      DO 30 L=LMIN,LMAX                                                     MAI  392
   30 WRITE (6,31) L,COE(L)                                                 MAI  393
   31 FORMAT (20X,I5,10X,F2C.5)                                             MAI  394
      WRITE (6,122) ICOUNT                                                  MAI  395
  122 FORMAT (//,9X,'NUMBER OF COE(L) RECORDS READ:',1X,I10)                MAI  396
C
C
C   READ IN SUBROUTINE NAME                                                 MAI  397
      READ (5,49) SUBNME                                                    MAI  398
   49 FORMAT (A6)                                                           MAI  399
C   READ IN SUBROUTINE COMMENTS                                             MAI  400
      READ (5,25) (COMENT(J), J=1,14)                                       MAI  401
C   DECIDE WHICH SUBROUTINE IS CALLED                                       MAI  402
      IF (SUBNME .EQ. SLI) GO TO 100                                        MAI  403
      IF (SUBNME .EQ. SEC) GO TO 101                                        MAI  404
      IF (SUBNME .EQ. VAN) GO TO 102                                        MAI  405
      IF (SUBNME .EQ. POL) GO TO 103                                        MAI  406
      IF (SUBNME .EQ. PIE) GO TO 106                                        MAI  407
      IF (SUBNME .EQ. CUT) GO TO 107                                        MAI  408
      GO TO 99                                                              MAI  409
  100 CONTINUE                                                              MAI  410
      READ (5,400) PHI1,XLMDA1,PHI2,XLMDA2,TOLERD,NRAD                      MAI  411
  400 FORMAT (5F10.5,I5)                                                    MAI  412
      CALL SLICE (PHI1,XLMDA1,PHI2,XLMDA2,TOLERD,NRAD)                      MAI  413
      GO TO 99                                                              MAI  414
  101 CONTINUE                                                              MAI  415
      READ (5,17) NSEC,NRAD                                                 MAI  416
      CALL SECTNS(NSEC,NRAD)                                                MAI  417
      GO TO 99                                                              MAI  418
  102 CONTINUE                                                              MAI  419
      READ (5,202) NRAD,RKM,MMAP,WMAP                                       MAI  420
      CALL VANDER (RKM,MMAP,WMAP,NRAD)                                      MAI  421
      GO TO 99                                                              MAI  422
  103 CONTINUE                                                              MAI  423
      READ (5,202) NRAD,ANGMAX,RKM                                          MAI  424
  202 FORMAT (I5,3F10.5)                                                    MAI  425
      NPOLE=1                                                               MAI  426
      CALL POLES (RKM,ANGMAX,NRAD,NPOLE)                                    MAI  427
      NPOLE=2                                                               MAI  428
      CALL POLES (RKM,ANGMAX,NRAD,NPOLE)                                    MAI  429
      GO TO 99                                                              MAI  430
  106 CONTINUE                                                              MAI  431
      READ (5,44) R1,R2,THETA1,THETA2,XLMDA1,XLMDA2,NSPACE,NSLRF            MAI  432
   44 FORMAT (6F10.5,2I5)                                                   MAI  433
      CALL PIECE (R1,R2,THETA1,THETA2,XLMDA1,XLMDA2,NSPACE,NSLRF)           MAI  434
      GO TO 99                                                              MAI  435
  107 CONTINUE                                                              MAI  436
      READ (5,123)PHI1,XLMDA1,PHI2,XLMDA2,DEPTH1,DEPTH2                     MAI  437
  123 FORMAT (8F10.5)                                                       MAI  438
      READ (5,124)NCUT,NHORZ,XMAGNI,ARCLNG,TOLERD                           MAI  439
  124 FORMAT (2I5,7F10.5)                                                   MAI  440
      CALL CUTS (PHI1,XLMDA1,PHI2,XLMDA2,DEPTH1,DEPTH2,ARCLNG,TOLERD,       MAI  441
     . NCUT,NHORZ,XMAGNI)                                                   MAI  442
   99 CONTINUE                                                              MAI  443
      STOP                                                                  MAI  444
      END                                                                   MAI  445
      SUBROUTINE CUTS (PHI1,XLMDA1,PHI2,XLMDA2,DEPTH1,DEPTH2,ARCLNG,        CUT    1
     . TOLERD,NCUT,NHORZ,XMAGNI)                                            CUT    2
C
```

```
C
C       *CUTS*                                                          CUT    3
C
C   FIND THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION ON EACH    CUT    4
C   HORIZONTAL LINE                                                     CUT    5
C   COMPUTE THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION AT POINTCUT    6
C      THIS SUBROUTINE COMPUTES THE RELATIVE DENSITY, DENSITY, OR       CUT    7
C DENSITY VARIATION ON VERTICAL RECTANGLES (CUTS) WHICH ARE             CUT    8
C PERPENDICULAR TO A GREAT CIRCLE CONNECTING TWO POINTS ON THE EARTH'S  CUT    9
C SURFACE AT INTERVALS EQUALLY SPACED ALONG THE GREAT CIRCLE SEGMENT.   CUT   10
C HENCE WHEN LOOKING DOWN ON THE SURFACE OF THE EARTH IT LOOKS LIKE     CUT   11
C THE LACINGS OF A FOOTBALL (WITH THE CUTS EXTENDING VERTICALLY         CUT   12
C DOWNWARDS)!                                                           CUT   13
C
C                                                                       CUT   14
C                  O     C     O     O                                  CUT   15
C                  O     C     O     O                                  CUT   16
C                  OXXXXXXCXXXXXXOXXXXXXO                               CUT   17
C                  O     C     O     O                                  CUT   18
C                  O     C     O     O                                  CUT   19
C                                                                       CUT   20
C                        CUTS   ! C                                     CUT   21
C                   GREAT CIRCLE: X                                     CUT   22
C
C
C     EACH CUT IS DISPLAYED ALONG WITH THE TOPOGRAPHY ALONG THE TRACK   CUT   23
C OF THE CUT.                                                           CUT   24
C
C     ALL CUTS HAVE THE SAME LENGTH AND DEPTH. ALL POINTS ON A VERTICAL CUT   25
C PRINT-OUT (PHOTO) LINE HAVE THE SAME LATITUDE AND LONGITUDE.          CUT   26
C
C     THE CUTS ARE DISPLAYED AS RECTANGLES, SO THAT THERE IS A CERTAIN  CUT   27
C AMOUNT OF DISTORTION. WE ARE LOOKING AT THE CUTS IN THE FOLLOWING     CUT   28
C WAY: START WHERE THE GREAT CIRCLE INTERSECTS THE EQUATOR AND GO NORTH CUT   29
C ALONG THE GREAT CIRCLE UNTIL THE CUTS ARE REACHED.                    CUT   30
C
C     THE TWO POINTS CONNECTED BY THE GREAT CIRCLE SEGMENT MAY BE       CUT   31
C CHOSEN AT WILL. THE NUMBER OF CUTS, THEIR LENGTH, AND THEIR DEPTH MAY CUT   32
C ALSO BE CHOSEN AT WILL. THERE IS ALWAYS A CUT AT EACH ENDPOINT OF     CUT   33
C THE GREAT CIRCLE SEGMENT.                                             CUT   34
C
C         NOTATION                                                      CUT   35
C
C     PHI1   = LATITUDE OF FIRST GREAT CIRCLE ENDPOINT IN DEGREES       CUT   36
C     XLMDA1 = LONGITUDE OF FIRST GREAT CIRCLE ENDPOINT IN DEGREES      CUT   37
C     PHI2   = LATITUDE OF SECOND GREAT CIRCLE ENDPOINT IN DEGREES      CUT   38
C     XLMDA2 = LONGITUDE OF SECOND GREAT CIRCLE ENDPOINT IN DEGREES     CUT   39
C     DEPTH1 = DEPTH TO LOWER CUT BOUNDARY IN KILOMETERS                CUT   40
C     DEPTH2 = DEPTH TO UPPER CUT BOUNDARY IN KILOMETERS                CUT   41
C     ARCLNG = LENGTH OF CUT IN DEGREES                                 CUT   42
C     TOLERC = TOLERANCE LIMIT IN DEGREES, BELOW WHICH A SMALL          CUT   43
C              DIFFERENCE IN LATITUDE OR LONGITUDE OF THE GREAT CIRCLE  CUT   44
C              ENDPOINTS IS SET EQUAL TO ZERO TO AVOID SINGULARITIES    CUT   45
C     NCUT   = NUMBER OF CUTS ALONG THE GREAT CIRCLE SEGMENT            CUT   46
C     NHORZ  = LENGTH OF CUT IN SPACES ACROSS PAGE (OR PHOTO)           CUT   47
C     XMAGNI = MAGNIFICATION OF DEPTH COMPARED TO LENGTH OF CUT (=1.0   CUT   48
C              FOR TRUE DEPTH TO LENGTH RATIO)                          CUT   49
C
C     SUBROUTINES CALLED:                                               CUT   50
C
C      1. ANGLE                                                         CUT   51
C      2. DENSTY                                                        CUT   52
C      3. TOPOGR                                                        CUT   53
C      4. VDG                                                           CUT   54
C
C     NOTES                                                             CUT   55
C
C      1. XLMDA1 .LE. XLMDA2.                                           CUT   56
C      2. DEPTH1 .GT. DEPTH2.                                           CUT   57
C      3. NHORZ IS ODD AND .LE. 121.                                    CUT   58
C      4. DEPTH1 IS USUALLY CHANGED SLIGHTLY BY THE SUBROUTINE TO MAKE  CUT   59
C         THE VERTICAL LENGTH OF THE CUTS AN INTEGER NUMBER OF SPACES   CUT   60
C         LONG ON THE PRINT-OUT PICTURE (OR DICOMED PHOTOGRAPH).        CUT   61
C      5. NCUT .GT. 1.                                                  CUT   62
C
C
C     SAMPLE INPUT DATA  (COLUMN 1 OF INPUT STARTS IN COLUMN 3 HERE)    CUT   63
C
C SUBNME                                    (FORMAT: A6)                CUT   64
C CUTS                                                                  CUT   65
C
C (COMENT(J), J=1,14)                       (FORMAT: 13A6,A2)           CUT   66
C   TONGA TRENCH                                                        CUT   67
C
C   PHI1    XLMDA1      PHI2   XLMDA2    DEPTH1  DEPTH2 (FORMAT:8F10.5) CUT   68
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C -23.44    185.11    -16.98    188.0     670.0     30.0                    CUT   67
C
C  NCUT NHORZ  XMAGNI  ARCLNG   TOLERD       (FORMAT: ,'5,7F10.5)           CUT   68
C     4  101     1.0     30.0   0.0001                                       CUT   69
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                               CUT   70
      INTEGER*2 IMAP(121), BETA(11)                                          CUT   71
      DIMENSION ALPHA(23),LCWH(1205,2)                                       CUT   72
      DIMENSION XMAP(121)                                                    CUT   73
      DIMENSION XLP(2),PH(2),FSI(2)                                          CUT   74
      DIMENSION XLAT(121),XLONG(121),XGRID(121),YGRID(121)                   CUT   75
      DIMENSION COMENT(14)                                                   CUT   76
      DIMENSION IWITE(121)                                                   CUT   77
      COMMON/BLKA/XMAP                                                       CUT   78
      COMMON/BLKC/F,PI,PI2,PIDV2,SCALE,NPHOTO,MAXSYM                         CUT   79
      COMMON/BLKD/ALPHA,LCWH                                                 CUT   80
      COMMON/BLKG/LMIN,LMAX,LLOW,LUP                                         CUT   81
      COMMON/BLKH/RADAVG,RCORE,RLOWER,RUPPER                                 CUT   82
      COMMON/BLKI/COMENT                                                     CUT   83
      COMMON/BLKJ/NDEN,REFDEN                                                CUT   84
      COMMON/BLKT/BETA                                                       CUT   85
      DATA DOT,EKS/1H.,1H)/                                                  CUT   86
C
C
      PI32=3.0D0*PI/2.0D0                                                    CUT   87
C
C   FIND MIDDLE OF SYMBOL/COLOR RANGE                                        CUT   88
      SYMMAX=MAXSYM                                                          CUT   89
      SYMPL=SYMMAX/2.0DC + 0.5D0                                             CUT   90
C
      R1=1.0DC - (DEPTH1/RADAVG)                                             CUT   91
      R2=1.0DC - (DEPTH2/RADAVG)                                             CUT   92
      HORZ=NHORZ - 1                                                         CUT   93
      XMICCL=(HORZ/2.0DC) + 1.0D0                                            CUT   94
      MIDDLE=(NHORZ - 1)/2                                                   CUT   95
      STRECH=5.0D0/(4.0D0*XMAGNI)                                            CUT   96
      IF (NPHOTO .EQ. 1) STRECH=1.0D0/XMAGNI                                 CUT   97
      FACTOR=HORZ/(R2*ARCLNG*STRECH*F)                                       CUT   98
      NRY=(R2 - R1)*FACTOR + 1.0D0                                           CUT   99
      RY=NRY                                                                 CUT  100
      R1=R2 - RY/FACTOR                                                      CUT  101
      DEPTH1=RADAVG*(1.0DC - R1)                                             CUT  102
      ARCKM=ARCLNG*RADAVG*R2*F                                               CUT  103
C   PRINT INPUT DATA                                                         CUT  104
      WRITE (6,70)                                                           CUT  105
 70   FORMAT (1H1)                                                           CUT  106
      WRITE (6,300)                                                          CUT  107
 300  FORMAT (///,10X,'SUBROUTINE CALLED: CUTS',///)                         CUT  108
      WRITE (6,311) (COMENT(J), J=1,14)                                      CUT  109
 311  FORMAT (10X,13A6,A2,///)                                               CUT  110
      WRITE (6,47) PHI1,XLMDA1                                               CUT  111
 47   FORMAT (3X,'FIRST GREAT CIRCLE POINT :',5X,'LATITUDE=',1X,F10.5,       CUT  112
     . 1X,'DEGREES',10X,'LONGITUDE=',1X,F10.5,1X,'DEGREES',//)               CUT  113
      WRITE (6,46) PHI2,XLMDA2                                               CUT  114
 46   FORMAT (3X,'SECOND GREAT CIRCLE POINT:',5X,'LATITUDE=',1X,F10.5,       CUT  115
     . 1X,'DEGREES',10X,'LONGITUDE=',1X,F10.5,1X,'DEGREES',//)               CUT  116
      WRITE (6,45) DEPTH1,DEPTH2                                             CUT  117
 45   FORMAT (5X,'DEPTHS BELOW SURFACE BETWEEN',1X,F10.5,1X,'KM AND',1X,     CUT  118
     . F10.5,1X,'KM',//)                                                     CUT  119
      WRITE (6,48) NCUT,NHORZ,XMAGNI,ARCLNG,ARCKM                            CUT  120
 48   FORMAT (5X,'NCUT=',I5,10X,'NHORZ=',I5,10X,'XMAGNI=',1X,F10.5,10X,     CUT  121
     . 'ARCLNG=',1X,F10.5,1X,'DEGREES = ',F10.5,1X,'KM',//)                  CUT  122
      NDEG=1                                                                 CUT  123
      RADMAP=26.0DC                                                          CUT  124
      WRITE (6,312) RADMAP                                                   CUT  125
 312  FORMAT (///, 8X,'X,Y GRID COORDINATES ON VAN DER GRINTEN MAP WITH      CUT  126
     .RADIUS',1X,F10.5,1X,'CM',//)                                           CUT  127
      CALL VDG (PHI1,XLMDA1,RADMAP,NDEG,X,Y)                                 CUT  128
      WRITE (6,313) X,Y                                                      CUT  129
 313  FORMAT (10X,'FIRST GREAT CIRCLE POINT:',3X,'XGRID=',1X,F8.3,1X,        CUT  130
     .'CM',10X,'YGRID=',1X,F8.3,1X,'CM',//)                                  CUT  131
      CALL VDG (PHI2,XLMDA2,RADMAP,NDEG,X,Y)                                 CUT  132
      WRITE (6,314) X,Y                                                      CUT  133
 314  FORMAT (10X,'SECOND GREAT CIRCLE POINT:',2X,'XGRID=',1X,F8.3,1X,       CUT  134
     . 'CM',10X,'YGRID=',1X,F8.3,1X,'CM',//)                                 CUT  135
C   CONVERT ANGLES FROM DEGREES TO RADIANS                                   CUT  136
      PHI1=PHI1*F                                                            CUT  137
      PHI2=PHI2*F                                                            CUT  138
      XLMDA1=XLMDA1*F                                                        CUT  139
      XLMDA2=XLMDA2*F                                                        CUT  140
      ARCLNG=ARCLNG*F                                                        CUT  141
      TOLER=TOLERD*F                                                         CUT  142
C   FIND XXI, OMEGA, COSXXI, SINXXI, COSOMG, SINOMG                          CUT  143
      TOLPHI=DSQRT(PHI1**2 + PHI2**2)                                        CUT  144
C   IS THE GREAT CIRCLE THE EQUATOR?                                         CUT  145
      IF (TOLPHI - TOLER) 79,80,80                                           CUT  146
 79   XXI=0.0DC                                                              CUT  147
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      CCSXXI=1.000                                                      CUT  148
      SINXXI=0.000                                                      CUT  149
      OMEGA=0.000                                                       CUT  150
      CCSOMG=1.000                                                      CUT  151
      SINOMG=0.000                                                      CUT  152
      PSI(1)=XLMDA1                                                     CUT  153
      PSI(2)=XLMDA2                                                     CUT  154
      GO TO 81                                                          CUT  155
   80 TOLLAM=DABS(XLMDA2 - XLMDA1)                                      CUT  156
C    IS THE GREAT CIRCLE A MERIDIAN?                                   CUT  157
      IF (TOLLAM - TOLER) 82,83,83                                      CUT  158
   82 XXI=PIDIV2                                                        CUT  159
      COSXXI=0.000                                                      CUT  160
      SINXXI=1.000                                                      CUT  161
      OMEGA=XLMDA1                                                      CUT  162
      CCSOMG=DCOS(OMEGA)                                                CUT  163
      SINOMG=DSIN(OMEGA)                                                CUT  164
      PSI(1)=PHI1                                                       CUT  165
      PSI(2)=PHI2                                                       CUT  166
      GO TO 81                                                          CUT  167
   83 CONTINUE                                                          CUT  168
      TANOMG=((DSIN(XLMDA1))*(DTAN(PHI2)) - (DSIN(XLMDA2))*(DTAN(PHI1)))CUT  169
     ./((DCOS(XLMDA1))*(DTAN(PHI2)) - (DCOS(XLMDA2))*(DTAN(PHI1)))      CUT  170
      OMEGA=DATAN(TANOMG)                                               CUT  171
      TANXXI=(DTAN(PHI2))/(DSIN(XLMDA2 - OMEGA))                        CUT  172
      IF (TANXXI) 52,52,53                                              CUT  173
   52 OMEGA=OMEGA + PI                                                  CUT  174
      TANXXI=-TANXXI                                                    CUT  175
   53 CONTINUE                                                          CUT  176
      XXI=DATAN(TANXXI)                                                 CUT  177
      IF (OMEGA) 55,54,54                                               CUT  178
   55 OMEGA=OMEGA + PI2                                                 CUT  179
   54 CONTINUE                                                          CUT  180
      COSOMG=DCOS(OMEGA)                                                CUT  181
      SINOMG=DSIN(OMEGA)                                                CUT  182
      CCSXXI=DCOS(XXI)                                                  CUT  183
      SINXXI=DSIN(XXI)                                                  CUT  184
      PH(1)=PHI1                                                        CUT  185
      XLM(1)=XLMDA1                                                     CUT  186
      PH(2)=PHI2                                                        CUT  187
      XLM(2)=XLMDA2                                                     CUT  188
      DO 60 I=1,2                                                       CUT  189
      B=XLM(I) - OMEGA                                                  CUT  190
      IF (B) 56,57,57                                                   CUT  191
   56 B=B + PI2                                                         CUT  192
   57 CONTINUE                                                          CUT  193
      COSPS=(DCOS(B))*(DCOS(PH(I)))                                     CUT  194
      CCSPS=DABS(COSPS)                                                 CUT  195
      SINPS=DSQRT(1.0D0 - CCSPS**2)                                     CUT  196
      CALL ANGLE (COSPS,SINPS,PS)                                       CUT  197
      IF (B - PI) 58,58,59                                              CUT  198
   58 CONTINUE                                                          CUT  199
      IF (B - PIDIV2) 64,64,61                                          CUT  200
   64 PSI(I)=PS                                                         CUT  201
      GO TO 60                                                          CUT  202
   61 PSI(I)=PI - PS                                                    CUT  203
      GO TO 60                                                          CUT  204
   59 CONTINUE                                                          CUT  205
      IF (B - PI32) 62,62,63                                            CUT  206
   62 PSI(I)=PI + PS                                                    CUT  207
      GO TO 60                                                          CUT  208
   63 PSI(I)=PI2 - PS                                                   CUT  209
   60 CONTINUE                                                          CUT  210
   81 CONTINUE                                                          CUT  211
      OMEGAC=OMEGA/F                                                    CUT  212
      XXIC=XXI/F                                                        CUT  213
C    PRINT XXI AND OMEGA IN DEGREES                                    CUT  214
C    XXI = ANGLE OF GREAT CIRCLE WITH EQUATOR                          CUT  215
C    OMEGA = LONGITUDE OF ASCENDING NODE OF GREAT CIRCLE, MEASURED     CUT  216
C    EASTWARD FROM GREENWICH                                           CUT  217
      WRITE (6,315)                                                     CUT  218
  315 FORMAT (////,8X,'GREAT CIRCLE LONGITUDE, INCLINATION TO EQUATOR,  CUT  219
     .AND TOLERANCE :',/)                                               CUT  220
      WRITE (6,77) OMEGAD,XXIC,TOLERD                                   CUT  221
   77 FORMAT (9X,'OMEGA=',14,F10.5,1X,'DEGREES',10X,'XXI=',1X,F10.5,1X, CUT  222
     . 'DEGREES',10X,'TOLERC=',1X,F15.10,1X,'DEGREES',///)              CUT  223
C
      DPSI=PSI(2) - PSI(1)                                              CUT  224
      XNCUT=NCUT                                                        CUT  225
      DLAMP=DPSI/(XNCUT - 1.0D0)                                        CUT  226
      CCSPSI=DCOS(PSI(I))                                               CUT  227
      SINPSI=DSIN(PSI(I))                                               CUT  228
      A11=CCSPSI*COSOMG - CCSXXI*SINOMG*SINPSI                          CUT  229
      A12=-SINPSI*COSOMG - COSXXI*SINOMG*COSPSI                         CUT  230
      A13=SINXXI*SINOMG                                                 CUT  231
      A21=CCSPSI*SINOMG + CCSXXI*COSOMG*SINPSI                          CUT  232
      A22=-SINPSI*SINOMG + COSXXI*COSOMG*COSPSI                         CUT  233
      A23=-SINXXI*COSOMG                                                CUT  234
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      A31=SINAXI*SINPSI                                                 CUT  235
      A32=SINAXI*COSPSI                                                 CUT  236
      A33=COSAXI                                                        CUT  237
C
      DO 86 J=1,12                                                      CUT  238
      XLAT(J)=0.0D0                                                     CUT  239
      XLONG(J)=0.0D0                                                    CUT  240
   86 CONTINUE                                                          CUT  241
C
C
C
      DO 69 I=1,NCUT                                                    CUT  242
      II=I - 1                                                          CUT  243
      WRITE (6,70)                                                      CUT  244
      WRITE (6,71) I                                                    CUT  245
   71 FORMAT (//,2X,'CUT NUMBER = ',I5,///)                             CUT  246
      XLMDAP=II*CLAMP                                                   CUT  247
      COSLPP=DCOS(XLMDAP)                                               CUT  248
      SINLPP=DSIN(XLMDAP)                                               CUT  249
      DO 87 K=1,NHORZ                                                   CUT  250
      FK=K                                                              CUT  251
      THETAP=PIDIV2 + (FK - XPICDL)*ANGLNG/HORZ                         CUT  252
      COSTPP=DCOS(THETAP)                                               CUT  253
      SINTPP=DSIN(THETAP)                                               CUT  254
      XP=SINTPP*COSLPP                                                  CUT  255
      YP=SINTPP*SINLPP                                                  CUT  256
      ZP=COSTPP                                                         CUT  257
      X=A11*XP + A12*YP + A13*ZP                                        CUT  258
      Y=A21*XP + A22*YP + A23*ZP                                        CUT  259
      Z=A31*XP + A32*YP + A33*ZP                                        CUT  260
      XSQYSQ=DSQRT(X**2 + Y**2)                                         CUT  261
      IF (XSQYSQ) 66,67,66                                              CUT  262
   67 PHIC=PIDIV2/F                                                     CUT  263
      THETA=0.000                                                       CUT  264
      IF (Z) 84,85,85                                                   CUT  265
   84 PHIC=-PIDIV2/F                                                    CUT  266
      THETA=PI                                                          CUT  267
   85 CONTINUE                                                          CUT  268
      GO TO 68                                                          CUT  269
   66 U=Z/XSQYSQ                                                        CUT  270
      PHI=DATAN(U)                                                      CUT  271
      THETA=PIDIV2 - PHI                                                CUT  272
      PHIC=PHI/F                                                        CUT  273
   68 CONTINUE                                                          CUT  274
      CALL ANGLE (X,Y,XLMDA)                                            CUT  275
      XLMDAC=XLMDA/F                                                    CUT  276
      IF (XLMDAC) 73,74,74                                              CUT  277
   73 XLMDAC=XLMDAC + 360.0D0                                           CUT  278
   74 CONTINUE                                                          CUT  279
      CALL TOPSON (THETA,XLMDA,H)                                       CUT  280
      IHITE(K)=2.0D0*H + 0.9DC + 23.0DC                                 CUT  281
      XLAT(K)=PHIC                                                      CUT  282
      XLONG(K)=XLMDAC                                                   CUT  283
      CALL VDC (PHIC,XLMDAC,RADMAP,NDEG,X,Y)                            CUT  284
      XGRID(K)=X                                                        CUT  285
      YGRID(K)=Y                                                        CUT  286
   87 CONTINUE                                                          CUT  287
      WRITE (6,88)                                                      CUT  288
   88 FORMAT (1X,'POINT',3X,'LATITUDE',5X,'LONGITUDE',3X,'XGRID',5X,    CUT  289
     . 'YGRID',11X,'POINT',3X,'LATITUDE',5X,'LONGITUDE',3X,'XGRID',5X,  CUT  290
     . 'YGRID')                                                         CUT  291
      WRITE (6,89)                                                      CUT  292
   89 FORMAT (9X,'(DEGREES)',4X,'(DEGREES)',4X,'(CM)',6X,'(CM)',19X,    CUT  293
     . '(DEGREES)',4X,'(DEGREES)',4X,'(CM)',6X,'(CM)',//)               CUT  294
      DO 90 K=1,MIDDLE                                                  CUT  295
      KK=K + MIDDLE                                                     CUT  296
      WRITE (6,91) K,XLAT(K),XLONG(K),XGRID(K),YGRID(K),KK,XLAT(KK),    CUT  297
     . XLONG(KK),XGRID(KK),YGRID(KK)                                    CUT  298
   91 FORMAT (2X,I3,3X,F10.5,3X,F10.5,2X,F8.3,2X,F8.3,10X,I3,3X,F10.5,  CUT  299
     . 3X,F10.5,2X,F8.3,2X,F8.3)                                        CUT  300
   90 CONTINUE                                                          CUT  301
      WRITE (6,92) NHORZ,XLAT(NHORZ),XLONG(NHORZ),XGRID(NHORZ),YGRID(NHOCUT  302
     .RZ)                                                               CUT  303
   92 FORMAT (61X,I3,3X,F10.5,3X,F10.5,2X,F8.3,2X,F8.3)                 CUT  304
C   INITIALIZE LINE VALUES                                             CUT  305
C   XPAP IS FOR PRINT-OUT PICTURE                                      CUT  306
C   TPAP IS FOR DICOMED PHOTO                                          CUT  307
      DO 4 K=1,121                                                      CUT  308
      TPAP(K) = BETA(11)                                                CUT  309
    4 XPAP(K)=ALPHA(23)                                                 CUT  310
      WRITE (6,78)                                                      CUT  311
      WRITE (6,204)                                                     CUT  312
  204 FORMAT (4X,'KM',49X,'(DOTS INDICATE SEA LEVEL)',/)                CUT  313
      DO 201 LP=1,41                                                    CUT  314
      LZ=42 - LP                                                        CUT  315
      FLZ=LZ                                                            CUT  316
      HEIGHT=(FLZ - 23.0D0)/2.000                                       CUT  317
      DO 202 K=1,NHORZ                                                  CUT  318
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      IF (LZ .EQ. 23) XMAP(K)=CUT                                       CUT  319
      IF (IHITE(K) .EQ. L7) XMAP(K)=EKS                                 CUT  320
  202 CONTINUE                                                          CUT  321
      WRITE (6,203) HEIGHT,(XMAP(K), K=1,121)                           CUT  322
  203 FORMAT (1X,F5.1,121A1)                                            CUT  323
      DO 201 K=1,NHORZ                                                  CUT  324
      XMAP(K)=ALPHA(23)                                                 CUT  325
  201 CONTINUE                                                          CUT  326
      NNY1=NNY + 1                                                      CUT  327
C
C
C   FIND THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION ON EACH    CUT  328
C   HORIZONTAL LINE                                                     CUT  329
      DO 2 LP=1,NNY1                                                    CUT  330
      FLP1=LP - 1                                                       CUT  331
      R=R2 - FLP1/FACTOR                                                CUT  332
      DO 3 K=1,NHORZ                                                    CUT  333
C   FIND THE X,Y,Z COORDINATES OF EACH POINT ON THE LINE                CUT  334
      FK=K                                                              CUT  335
      THETAP=PIDIV2 + (FK - XP100L)*ARCLNG/HORZ                         CUT  336
      COSTHP=COS(THETAP)                                                CUT  337
      SINTHP=SIN(THETAP)                                                CUT  338
      XP=R*SINTHP*COSLMP                                                CUT  339
      YP=R*SINTHP*SINLPP                                                CUT  340
      ZP=R*COSTHP                                                       CUT  341
      X=A11*XP + A12*YP + A13*ZP                                        CUT  342
      Y=A21*XP + A22*YP + A23*ZP                                        CUT  343
      Z=A31*XP + A32*YP + A33*ZP                                        CUT  344
C   IS THE POINT IN THE CORE?                                           CUT  345
      IF (R - RCORE) 28,21,27                                           CUT  346
   28 JNUM=22                                                           CUT  347
C     9 IS USED FOR CORE                                                CUT  348
      GO TO 29                                                          CUT  349
   27 CONTINUE                                                          CUT  350
C   IS THE POINT BELOW RLOWER?                                          CUT  351
      IF (R - RLOWER) 101,102,102                                       CUT  352
  101 DEN=0.0D0                                                         CUT  353
      GO TO 103                                                         CUT  354
  102 CONTINUE                                                          CUT  355
C   FIND THE SPHERICAL POLAR COORDINATES OF POINT                       CUT  356
      XSQYSQ=CSQRT(X**2 + Y**2)                                         CUT  357
      IF (Z) 24,25,24                                                   CUT  358
   25 THETA=PIDIV2                                                      CUT  359
      GO TO 26                                                          CUT  360
   24 U=XSQYSQ/Z                                                        CUT  361
      THETA=DATAN(U)                                                    CUT  362
      IF (Z) 44,26,26                                                   CUT  363
   44 THETA=PI + THETA                                                  CUT  364
   26 CONTINUE                                                          CUT  365
      CALL ANGLE(X,Y,XLMDA)                                             CUT  366
C   FIND THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION AT POINT   CUT  367
      CALL DENSTY (R,THETA,XLMDA,NOEN,REPDEN,DEN)                       CUT  368
  103 CONTINUE                                                          CUT  369
C   PUT THE RIGHT SYMBOL/NUMBER IN XMAP(K)/TMAP(K)                      CUT  370
      XS=(DEN/SCALE) + 0.1D0                                            CUT  371
      JNUM=SYMBL + XS                                                   CUT  372
      IF (JNUM .LE. 1) JNUM=1                                           CUT  373
      IF (JNUM .GE. MAXSYM) JNUM=MAXSYM                                 CUT  374
   29 XMAP(K)=ALPHA(JNUM)                                               CUT  375
      TMAP(K) = BETA(JNUM)                                              CUT  376
    3 CONTINUE                                                          CUT  377
C   PRINT THE LINE                                                      CUT  378
      WRITE (6,14) (XMAP(K), K=1,121)                                   CUT  379
   14 FORMAT (4X,121A1)                                                 CUT  380
C     WRITE (10,100)(TMAP(K), K=1,121)                                  CUT  381
C 100 FORMAT (121I2)                                                    CUT  382
C   RESET THE LINE                                                      CUT  383
      DO 15 K=1,121                                                     CUT  384
      XMAP(K)=ALPHA(23)                                                 CUT  385
      TMAP(K) = BETA(11)                                                CUT  386
   15 CONTINUE                                                          CUT  387
    2 CONTINUE                                                          CUT  388
   69 CONTINUE                                                          CUT  389
      RETURN                                                            CUT  390
      END                                                               CUT  391
      SUBROUTINE PIECE (R1,R2,THETA1,THETA2,XLMDA1,XLMDA2,NSPACE,NSURF) PIE    1
C
C
C        *PIECE*                                                        PIE    2
C
C     THIS SUBROUTINE COMPUTES THE RELATIVE DENSITY, DENSITY, OR       PIE    3
C DENSITY VARIATION ON A NUMBER OF SPHERICAL RECTANGLES, ALL WITH THE   PIE    4
C SAME ANGULAR COORDINATES BUT POSITIONED AT DIFFERENT DEPTHS.          PIE    5
C
C     A SPHERICAL RECTANGLE IS THE AREA ON THE SURFACE OF A SPHERE      PIE    6
C BOUNDED BY TWO FIXED LATITUDES AND TWO FIXED LONGITUDES.              PIE    7
C
C     SPHERICAL RECTANGLES ARE ALWAYS COMPUTED FOR RADIAL DISTANCES R1  PIE    8
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C AND R2, WITH THE OTHERS (IF ANY) SANDWICHED IN BETWEEN THESE TWO.      PIE    9
C
C     THE SPHERICAL RECTANGLES ARE DISPLAYED AS RECTANGLES WITH THE      PIE   10
C EAST-WEST DIRECTION RUNNING HORIZONTALLY ACROSS THE PAGE (PHOTO). SO   PIE   11
C THERE IS A CERTAIN AMOUNT OF DISTORTION.                               PIE   12
C
C
C          NOTATION                                                      PIE   13
C
C     R1      = RADIAL DISTANCE OF LOWEST RECTANGLE IN KILOMETERS        PIE   14
C     R2      = RADIAL DISTANCE OF HIGHEST RECTANGLE IN KILOMETERS       PIE   15
C     THETA1  = COLATITUDE OF NORTHERN BOUNDARY OF THE RECTANGLES IN     PIE   16
C               DEGREES                                                  PIE   17
C     THETA2  = COLATITUDE OF SOUTHERN BOUNDARY OF THE RECTANGLES IN     PIE   18
C               DEGREES                                                  PIE   19
C     XLMDA1  = LONGITUDE OF THE WESTERN BOUNDARY OF THE RECTANGLES IN   PIE   20
C               DEGREES                                                  PIE   21
C     XLMDA2  = LONGITUDE OF THE EASTERN BOUNDARY OF THE RECTANGLES IN   PIE   22
C               DEGREES                                                  PIE   23
C     NSPACE  = LENGTH OF THE NORTHERN AND SOUTHERN BOUNDARIES IN        PIE   24
C               HORIZONTAL SPACES ACROSS THE PAGE (PHOTO).               PIE   25
C     NSURF   = NUMBER OF RECTANGLES DESIRED                             PIE   26
C
C
C     SUBROUTINES CALLED:                                                PIE   27
C
C
C      1. CENSTY                                                         PIE   28
C
C
C     NOTES                                                              PIE   29
C
C      1. R2 .GT. R1.                                                    PIE   30
C      2. THETA2 .GT. THETA1.                                            PIE   31
C      3. XLMDA2 .GT. XLMDA1.                                            PIE   32
C      4. NSPACE .LE. 120.                                               PIE   33
C      5. NSURF .GT. 1.                                                  PIE   34
C
C
C     SAMPLE INPUT DATA   (COLUMN 1 OF INPUT STARTS IN COLUMN 3 HERE)    PIE   35
C
C SUBNME                                  (FORMAT: A6)                   PIE   36
C PIECE                                                                  PIE   37
C
C (COMENT(J), J=1,14)                     (FORMAT: 13A6,A2)              PIE   38
C    HAWAII                                                              PIE   39
C
C   R1        R2     THETA1    THETA2     XLMDA1    XLMDA2   NSPACE NSURFPIE   40
C                                        (FORMAT: 6F10.5,215)            PIE   41
C 3121.0    6321.0    50.0      80.0      180.0     210.0        80    3PIE   42
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                           PIE   43
      INTEGER*2 XMAP(121), BETA(11)                                      PIE   44
      DIMENSION ALPHA(23),LCWRI(205,2)                                   PIE   45
      DIMENSION XMAP(121)                                                PIE   46
      DIMENSION COMENT(14)                                               PIE   47
      COMMON/BLKA/XMAP                                                   PIE   48
      COMMON/BLKC/F,PI,PI2,PIDIV2,SCALE,NPHOTO,MAXSYM                    PIE   49
      COMMON/BLKD/ALPHA,LCWRI                                            PIE   50
      COMMON/BLKG/LMIN,LMAX,LLOW,LUP                                     PIE   51
      COMMON/BLKH/RADAVG,RCORE,RLOWER,RUPPER                             PIE   52
      COMMON/BLKI/COMENT                                                 PIE   53
      COMMON/BLKJ/NDEN,REFDEN                                            PIE   54
      COMMON/BLKT/BETA                                                   PIE   55
C
C   PRINT INPUT DATA                                                     PIE   56
      WRITE (6,300)                                                      PIE   57
  300 FORMAT (///,10X,'SUBROUTINE CALLED: PIECE',///)                    PIE   58
      WRITE (6,311) (COMENT(J), J=1,14)                                  PIE   59
  311 FORMAT (10X,13A6,A2,///)                                           PIE   60
C
C   FIND MIDDLE OF SYMBOL/COLOR RANGE                                    PIE   61
      SYMMAX=MAXSYM                                                      PIE   62
      SYMMID=SYMMAX/2.000 + 0.500                                        PIE   63
C
      STRECH=5.000/4.000                                                 PIE   64
      IF (NPHOTO .EQ. 1) STRECH=1.000                                    PIE   65
C
      WRITE (6,1)                                                        PIE   66
    1 FORMAT (1H1)                                                       PIE   67
      NSP1=NSPACE + 1                                                    PIE   68
      SURFCE=NSURF                                                       PIE   69
      SPACE=NSPACE                                                       PIE   70
      DR=(R2 - R1)/(SURFCE - 1.000)                                      PIE   71
      DLMDA=(XLMDA2 - XLMDA1)/SPACE                                      PIE   72
      DTHETA=DLMDA*STRECH                                                PIE   73
      NTHETA=(THETA2 - THETA1)/DTHETA + 0.500000100                      PIE   74
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      TH=NTHETA                                                          PIE   75
      NTH1=NTHETA + 1                                                    PIE   76
      THETA2=THETA1 + TH*DTHETA                                          PIE   77
C   DR = DISTANCE BETWEEN SURFACES                                       PIE   78
C   DTHETA = LATITUDE DIFFERENCE BETWEEN NEIGHBORING POINTS              PIE   79
C   XLMDA  = LONGITUDE DIFFERENCE BETWEEN NEIGHBORING POINTS             PIE   80
C
      WRITE (6,2) R1,R2,DR                                               PIE   81
 2    FORMAT (2X,'R1=',F10.3,1X,'KM',10X,'R2=',F10.3,1X,'KM',10X,'DR=',  PIE   82
     . F10.3,1X,'KM',///)                                                PIE   83
      WRITE (6,3) THETA1,THETA2,DTHETA                                   PIE   84
 3    FORMAT (2X,'THETA1=',F10.4,1X,'DEGREES',10X,'THETA2=',F10.4,1X,    PIE   85
     . 'DEGREES',10X,'DTHETA=',F10.4,1X,'DEGREES',///)                   PIE   86
      WRITE (6,5) XLMDA1,XLMDA2,DLMDA                                    PIE   87
 5    FORMAT (2X,'XLMDA1=',F10.4,1X,'DEGREES',10X,'XLMDA2=',F10.4,1X,    PIE   88
     . 'DEGREES',10X,'DLMDA=',F10.4,1X,'DEGREES',///)                    PIE   89
C
C   NORMALIZE DISTANCES TO EARTH RADIUS                                  PIE   90
      R1=R1/RADAVG                                                       PIE   91
      R2=R2/RADAVG                                                       PIE   92
      DR=DR/RADAVG                                                       PIE   93
C   CONVERT ANGLES FROM DEGREES TO RADIANS                               PIE   94
      THETA1=THETA1*F                                                    PIE   95
      THETA2=THETA2*F                                                    PIE   96
      DTHETA=DTHETA*F                                                    PIE   97
      XLMDA1=XLMDA1*F                                                    PIE   98
      XLMDA2=XLMDA2*F                                                    PIE   99
      DLMDA=DLMDA*F                                                      PIE  100
C
      WRITE (6,1)                                                        PIE  101
C
C   INITIALIZE LINE VALUES                                               PIE  102
C   XMAP IS FOR PRINT-OUT PICTURE                                        PIE  103
C   TMAP IS FOR DISCMEC PHOTO                                            PIE  104
      DO 4 K=1,121                                                       PIE  105
      TMAP(K)=BETA(11)                                                   PIE  106
 4    XMAP(K)=ALPHA(23)                                                  PIE  107
C
      R=R2 + DR                                                          PIE  108
C
      DO 10 ISURF=1,NSURF                                                PIE  109
      R=R - DR                                                           PIE  110
      THETA=THETA1 - DTHETA                                              PIE  111
      DO 9 ITHETA=1,NTH1                                                 PIE  112
      THETA=THETA + DTHETA                                               PIE  113
      XLMDA=XLMDA1 - DLMDA                                               PIE  114
      DO 8 K=1,NSP1                                                      PIE  115
      XLMDA=XLMDA + DLMDA                                                PIE  116
C   COMPUTE THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION AT POINTPIE  117
      CALL DENSTY (R,THETA,XLMDA,NDEN,RLFDEN,DEN)                        PIE  118
C   PUT THE RIGHT SYMBOL/NUMBER IN XMAP(K)/TMAP(K)                       PIE  119
      XS=(DEN/SCALE) + 0.5DC                                             PIE  120
      JNUM=SYMBL + XS                                                    PIE  121
      IF (JNUM .LE. 1) JNUM=1                                            PIE  122
      IF (JNUM .GE. MAXSYM) JNUM=MAXSYM                                  PIE  123
 29   XMAP(K)=ALPHA(JNUM)                                                PIE  124
      TMAP(K) = BETA(JNUM)                                               PIE  125
 8    CONTINUE                                                           PIE  126
C   PRINT THE LINE                                                       PIE  127
      WRITE (6,14) (XMAP(K), K=1,121)                                    PIE  128
 14   FORMAT (5X,121A1)                                                  PIE  129
C     WRITE (10,100)(TMAP(K), K=1,121)                                   PIE  130
C 100 FORMAT (12I12)                                                     PIE  131
 9    CONTINUE                                                           PIE  132
      WRITE (6,1)                                                        PIE  133
 10   CONTINUE                                                           PIE  134
      RETURN                                                             PIE  135
      END                                                                PIE  136
      SUBROUTINE POLES (RKM,ANGMAX,NRAD,NPOLE)                           POL    1
C
C        *POLES*                                                         POL    2
C
C     THIS SUBROUTINE COMPUTES THE RELATIVE DENSITY, DENSITY, OR       POL    3
C DENSITY VARIATION ON A SURFACE OF CHOSEN RADIUS USING THE POLAR      POL    4
C ORTHOGRAPHIC PROJECTION.                                             POL    5
C
C     IT DISPLAYS THE NORTH POLAR REGION IF NPOLE=1 AND THE SOUTH      POL    6
C POLAR REGION IF NPOLE=2.                                             POL    7
C
C
C     NOTATION                                                         POL    8
C
C     RKM    = RADIAL DISTANCE OF MAP SURFACE IN KILOMETERS            POL    9
C     ANGMAX = ANGULAR DISTANCE FROM POLE TO MAP PERIMETER IN DEGREES  POL   10
C     NRAD   = RADIUS OF THE MAP IN HORIZONTAL SPACES ACROSS THE PAGE  POL   11
C              (PHOTO)                                                 POL   12
C     NPOLE  = 1 FOR NORTH POLAR MAP; =2 FOR SOUTH POLAR MAP           POL   13
C
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C
C     SUBROUTINES CALLED:                                                    POL   14
C
C      1. ANGLE                                                              POL   15
C      2. CIRC                                                               POL   16
C      3. DENSTY                                                             POL   17
C
C
C     NOTES                                                                  POL   18
C
C      1. ANGMAX .LT. 90 DEGREES.                                            POL   19
C      2. NRAD .LE. 60.                                                      POL   20
C
C
C     SAMPLE INPUT DATA   (COLUMN 1 OF INPUT STARTS IN COLUMN 3 HERE)        POL   21
C
C SUBNME                                  (FORMAT: A6)                      POL   22
C POLES                                                                     POL   23
C
C  (COMENT(J), J=1,14)                    (FORMAT: 13A6,A2)                 POL   24
C SURFACE DENSITY DISTRIBUTION                                              POL   25
C
C  NRAD  ANGMAX    RKM                    (FORMAT: I5,3F10.5)               POL   26
C    34  50.0     6371.0                                                    POL   27
C
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                              POL   28
      INTEGER*2 TMAP(121), BETA(11)                                         POL   29
      DIMENSION ALPHA(23),LCWHI(205,2)                                      POL   30
      DIMENSION XMAP(121)                                                   POL   31
      DIMENSION COMENT(14)                                                  POL   32
      COMMON/BLKA/XMAP                                                      POL   33
      COMMON/BLKC/F,PI,PI2,PIDIV2,SCALE,NPHOTO,MAXSYM                       POL   34
      COMMON/BLKD/ALPHA,LCWHI                                               POL   35
      COMMON/BLKG/LMIN,LMAX,LLOW,LUP                                        POL   36
      COMMON/BLKH/RADAVG,RCORE,RLOWER,RUPPER                                POL   37
      COMMON/BLKI/COMENT                                                    POL   38
      COMMON/BLKJ/NDEN,REFDEN                                               POL   39
      COMMON/BLKK/BETA                                                      POL   40
C
C   PRINT INPUT DATA                                                        POL   41
      WRITE (6,16)                                                          POL   42
      WRITE (6,300)                                                         POL   43
  300 FORMAT (///,10X,'SUBROUTINE CALLED: POLES',///)                       POL   44
      WRITE (6,311) (COMENT(J), J=1,14)                                     POL   45
  311 FORMAT (10X,13A6,A2,///)                                              POL   46
      WRITE (6,301) RKM                                                     POL   47
  301 FORMAT (10X,'RKM =',1X,F10.3,1X,'KM',10X,'(RADIAL DISTANCE OF SURFPOL 48
     .ACE)',///)                                                            POL   49
      WRITE (6,302) NRAD                                                    POL   50
  302 FORMAT (10X,'NRAD =',1X,I4,10X,'(RADIUS OF MAP IN HORIZONTAL SPACEPOL 51
     .S)',//)                                                               POL   52
      WRITE (6,303) ANGMAX                                                  POL   53
  303 FORMAT (10X,'ANGMAX =',1X,F10.5,1X,'DEGREES',10X,'(MAXIMUM COLATITPOL 54
     .UDE)',///)                                                            POL   55
C
      R=RKM/RADAVG                                                          POL   56
      ANGM=ANGMAX*F                                                         POL   57
      SANG=DSIN(ANGM)                                                       POL   58
C
C   FIND MIDDLE OF SYMBOL/COLOR RANGE                                       POL   59
      SYMMAX=MAXSYM                                                         POL   60
      SYMEL=SYMMAX/2.0D0 + 0.5D0                                            POL   61
C
C   COMPUTE NUMBER OF HORIZONTAL LINES IN MAP                               POL   62
      NRDSEC=NRAD                                                           POL   63
      RADSEC=NRAD                                                           POL   64
      NRY=4*NRDSEC/5                                                        POL   65
      IF (NPHOTO .EQ. 1) NRY=NRDSEC                                         POL   66
      NY=2*NRY + 1                                                          POL   67
      NRY1=NRY + 1                                                          POL   68
      NY1=NRY1                                                              POL   69
CC    FIND LEFT AND RIGHT LIMITS OF MAP BY CALLING CIRC                     POL   70
      CALL CIRC(NRDSEC)                                                     POL   71
C
      DO 10 NUMMAP=1,1                                                      POL   72
C
C   INITIALIZE LINE VALUES                                                  POL   73
C   XMAP IS FOR PRINT-OUT PICTURE                                           POL   74
C   TMAP IS FOR DICOMED PHOTO                                               POL   75
      DO 4 K=1,121                                                          POL   76
      TMAP(K) = BETA(11)                                                    POL   77
    4 XMAP(K)=ALPHA(23)                                                     POL   78
C
      WRITE (6,16)                                                          POL   79
   16 FORMAT (1H1)                                                          POL   80
      IF (NPOLE .EQ. 1) WRITE (6,30)                                        POL   81
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      IF (NPOLE .EQ. 2) WRITE (6,31)                                    POL   82
 30   FORMAT (10X,'NORTH POLE',//////)                                  POL   83
 31   FORMAT (10X,'SOUTH POLE',//////)                                  POL   84
C
C   FIND THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION ON EACH    POL   85
C   HORIZONTAL LINE                                                     POL   86
      DO 2 LP=1,NY                                                      POL   87
      LZ=NY -LP + 1                                                     POL   88
      FLZ=LZ                                                            POL   89
      KMIN=LOWHI(LP,1)                                                  POL   90
      KMAX=LOWHI(LP,2)                                                  POL   91
      DO 3 K=KMIN,KMAX                                                  POL   92
C   FIND THE X,Y,Z COORDINATES OF EACH POINT ON THE LINE                POL   93
      FK=K                                                              POL   94
      X=FK - 61.0D0                                                     POL   95
      STRECH=9.0D0/4.0DC                                                POL   96
      IF (NPHCTO .EQ. 1) STRECH=1.0D0                                   POL   97
      Y=(FLZ - RY1)*STRECH                                              POL   98
C   FIND THE SPHERICAL POLAR COORDINATES OF POINT                       POL   99
      CALL ANGLE(X,Y,XLPDA)                                             POL  100
      IF (NPOLE .EQ. 2) XLMDA=PI2 - XLMDA                               POL  101
      XSQYSQ=DSQRT(X**2 + Y**2)                                         POL  102
      SINTHE=XSQYSQ*SANG/RADSEC                                         POL  103
      IF (SINTHE - 1.0DC) 202,201,201                                   POL  104
 201  WRITE (6,203) NRAD,NRCSEC,NY,NRY,NRY1,LP,LZ,K                     POL  105
 203  FORMAT (5X, 1115)                                                 POL  106
      WRITE (6,204) RADSEC,RY1,FLZ,FK,X,Y,XSQYSQ,SANG,SINTHE            POL  107
 204  FORMAT (5X,11F10.5)                                               POL  108
      GO TO 10                                                          POL  109
 202  CONTINUE                                                          POL  110
      COSTHE=DSQRT(1.0DC - SINTHE**2)                                   POL  111
      CALL ANGLE(COSTHE,SINTHE,THETA)                                   POL  112
      IF (NPOLE .EQ. 2) THETA=PI - THETA                                POL  113
C   COMPUTE THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION AT POINTPOL  114
      CALL DENSTY (R,THETA,XLPDA,NDEN,REFDEN,DEN)                       POL  115
C   PUT THE RIGHT SYMBOL/NUMBER IN XMAP(K)/TMAP(K)                      POL  116
      XS=(DEN/SCALE) + 0.5DC                                            POL  117
      JNUM=SYMBL + XS                                                   POL  118
      IF (JNUM .LE. 1) JNUM=1                                           POL  119
      IF (JNUM .GE. MAXSYM) JNUM=MAXSYM                                 POL  120
 29   XMAP(K)=ALPHA(JNUM)                                               POL  121
      TMAP(K) = BETA(JNUM)                                              POL  122
 3    CONTINUE                                                          POL  123
C
C   PRINT THE LINE                                                      POL  124
      WRITE (6,14) (XMAP(K), K=1,121)                                   POL  125
 14   FORMAT (5X,121A1)                                                 POL  126
C     WRITE (10,100)(TMAP(K), K=1,121)                                  POL  127
C 100 FORMAT (121I2)                                                    POL  128
C
C   RESET THE LINE                                                      POL  129
      DO 15 K=KMIN,KMAX                                                 POL  130
      XMAP(K)=ALPHA(23)                                                 POL  131
      TMAP(K) = BETA(11)                                                POL  132
 15   CONTINUE                                                          POL  133
C
 2    CONTINUE                                                          POL  134
C
 10   CONTINUE                                                          POL  135
      RETURN                                                            POL  136
      END                                                               POL  137
      SUBROUTINE SECTNS(NSEC,NRAD)                                      SEC    1
C
C
C        *SECTNS*                                                       SEC    2
C
C     THIS SUBROUTINE COMPUTES THE RELATIVE DENSITY, DENSITY, OR        SEC    3
C DENSITY VARIATION ON A NUMBER OF PLANES WHICH SLICE THROUGH THE EARTH SEC    4
C PARALLEL TO THE EQUATOR. THE INTERSECTION OF THE EARTH WITH A PLANE   SEC    5
C IS CALLED A SECTION.                                                  SEC    6
C
C     ONE SECTION ALWAYS CONTAINS THE EQUATOR. THE SECTIONS ARE EQUALLY SEC    7
C SPACED BETWEEN THE NORTH POLE AND THE SOUTH POLE. FOR EXAMPLE, IF     SEC    8
C THREE SECTIONS ARE CHOSEN, ONE CONTAINS THE EQUATORIAL PLANE AND THE  SEC    9
C OTHER TWO SECTIONS ARE SPACED ONE-HALF EARTH RADIUS NORTH AND SOUTH   SEC   10
C OF THE EQUATOR (ASSUMING NO CRUST IS STRIPPED OFF).                   SEC   11
C
C
C          NOTATION                                                     SEC   12
C
C     NSEC   = NUMBER OF SECTIONS CHOSEN                                SEC   13
C     NRAD   = RADIUS OF EQUATORIAL SECTION IN HORIZONTAL SPACES ACROSS SEC   14
C              PAGE (PHOTO)                                             SEC   15
C
C
C     SUBROUTINES CALLED:                                               SEC   16
C
C      1. ANGLE                                                         SEC   17
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C      2. CIRC                                                          SEC   18
C      3. CENSTY                                                        SEC   19
C
C
C     NOTES                                                             SEC   20
C
C      1. NSEC IS ODD.                                                  SEC   21
C      2. NRAD .LE. 60.                                                 SEC   22
C
C
C     SAMPLE INPUT DATA  (COLUMN 1 OF INPUT STARTS IN COLUMN 3 HERE)    SEC   23
C
C SUBNME                                  (FORMAT: A                   SEC   24
C SECTNS                                                               SEC   25
C
C (COMENT(J), J=1,14)                     (FORMAT: 13A6,A2)            SEC   26
C FIVE SECTIONS CHOSEN                                                 SEC   27
C
C  NSEC  NRAD                             (FORMAT: 4I5)                SEC   28
C     5    60                                                          SEC   29
C
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                         SEC   30
      INTEGER*2 TMAP(121), BETA(11)                                    SEC   31
      DIMENSION ALPHA(23),LCWPI(205,2)                                 SEC   32
      DIMENSION XMAP(121)                                              SEC   33
      DIMENSION COMENT(14)                                             SEC   34
      COMMON/BLKA/XMAP                                                 SEC   35
      COMMON/BLKC/F,PI,PI2,PIDIV2,SCALE,NPHOTO,MAXSYM                  SEC   36
      COMMON/BLKD/ALPHA,LCWPI                                          SEC   37
      COMMON/BLKG/LPIN,LMAX,LLOW,LUP                                   SEC   38
      COMMON/BLKH/RADAVG,RCORE,RLOWER,RUPPER                           SEC   39
      COMMON/BLKI/COMENT                                               SEC   40
      COMMON/BLKJ/NDEN,REFDEN                                          SEC   41
      COMMON/BLKT/BETA                                                 SEC   42
C
C   PRINT INPUT DATA                                                   SEC   43
      WRITE (6,16)                                                     SEC   44
      WRITE (6,300)                                                    SEC   45
 300  FORMAT (///,10X,'SUBROUTINE CALLED: SECTNS',///)                 SEC   46
      WRITE (6,311) (COMENT(J), J=1,14)                                SEC   47
 311  FORMAT (10X,13A6,A2,///)                                         SEC   48
      WRITE (6,301) NSEC                                               SEC   49
 301  FORMAT (10X,'NSEC =',1X,I4,10X,'(NUMBER OF SECTIONS)',//)        SEC   50
      WRITE (6,302) NRAD                                               SEC   51
 302  FORMAT (10X,'NRAD =',1X,I4,10X,'(RADIUS OF EQUATOR IN HORIZONTAL SSEC   52
     .PACES)',//)                                                      SEC   53
C
C   FIND MIDDLE OF SYMBOL/COLOR RANGE                                  SEC   54
      SYMMAX=MAXSYM                                                    SEC   55
      SYMMI=SYMMAX/2.000 + 0.500                                       SEC   56
C
      NHEMI=(NSEC - 1)/2 + 1                                           SEC   57
      FRAD=NRAD                                                        SEC   58
      HEMI=NHEMI                                                       SEC   59
C
C   DO EACH SECTION                                                    SEC   60
      DO 10 JJ=1,NSEC                                                  SEC   61
      FJJ=NHEMI - JJ                                                   SEC   62
      IF (JJ .EQ. NHEMI) GO TO 21                                      SEC   63
      SQUARE=(FRAD**2)*(1.000 - (FJJ**2)/(HEMI**2))                    SEC   64
      RADSEC=DSQRT(SQUARE)                                             SEC   65
      ZR=FRAD*(FJJ/HEMI)                                               SEC   66
      NRDSEC=RADSEC                                                    SEC   67
      RADSEC=NRDSEC                                                    SEC   68
      GO TO 22                                                         SEC   69
 21   NRDSEC=NRAD                                                      SEC   70
      THETA=PIDIV2                                                     SEC   71
      RADSEC=FRAD                                                      SEC   72
C
 22   CONTINUE                                                         SEC   73
C   COMPUTE NUMBER OF HORIZONTAL LINES IN MAP                          SEC   74
      NRY=4*NRDSEC/5                                                   SEC   75
      IF (NPHOTO .EQ. 1) NRY=NRDSEC                                    SEC   76
      NY=2*NRY + 1                                                     SEC   77
      NRY1=NRY + 1                                                     SEC   78
      RY1=NRY1                                                         SEC   79
C   FIND LEFT AND RIGHT LIMITS OF MAP BY CALLING CIRC                  SEC   80
      CALL CIRC(NRDSEC)                                                SEC   81
C
C   INITIALIZE LINE VALUES                                             SEC   82
C   XMAP IS FOR PRINT-OUT PICTURE                                      SEC   83
C   TMAP IS FOR DECOMED PHOTO                                          SEC   84
      DO 4 K=1,121                                                     SEC   85
      TMAP(K) = BETA(11)                                               SEC   86
 4    XMAP(K)=ALPHA(23)                                                SEC   87
C
C   SPACE DOWN THE PAGE                                                SEC   88
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      WRITE (6,16)                                                    SEC   89
 16   FORMAT (1H1)                                                    SEC   90
      NSPACE=128 - NRY                                                SEC   91
      DO 17 KK=1,NSPACE                                               SEC   92
 17   WRITE (6,18) ALPHA(23)                                          SEC   93
 18   FORMAT (10X,1A1)                                                SEC   94
C
      Z=FJJ*RLPPER/HEM1                                               SEC   95
C     FIND THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION ON EACH SEC   96
C     HORIZONTAL LINE                                                 SEC   97
      DO 2 LP=1,NY                                                    SEC   98
C     FIND THE X,Y,Z COORDINATES OF EACH POINT ON THE LINE            SEC   99
      LZ=NY -LP + 1                                                   SEC  100
      FLZ=LZ                                                          SEC  101
      STRECH=5.0D0/4.0DC                                              SEC  102
      IF (NPHCTD .EQ. 1) STRECH=1.0D0                                 SEC  103
      Y=(FLZ - RY1)*(STRECH*RLPPER)/RADSEC                            SEC  104
      KMIN=LOWHI(LP,1)                                                SEC  105
      KMAX=LOWHI(LP,2)                                                SEC  106
      DO 3 K=KMIN,KMAX                                                SEC  107
      FK=K                                                            SEC  108
      X=(FK - 61.0D0)*(RUPPER/RADSEC)                                 SEC  109
C     FIND THE SPHERICAL POLAR COORDINATES OF POINT                   SEC  110
      R=DSQRT(X**2 + Y**2 + Z**2)                                     SEC  111
C     IS THE POINT IN THE CORE?                                       SEC  112
      IF (R - RCORE) 28,27,27                                         SEC  113
 28   JNUM=22                                                         SEC  114
C     $ IS USED FOR CORE                                              SEC  115
      GO TO 29                                                        SEC  116
 27   CONTINUE                                                        SEC  117
C     IS THE POINT BELOW RLOWER?                                      SEC  118
      IF (R - RLOWER) 101,102,102                                     SEC  119
 101  DEN=0.0D0                                                       SEC  120
      GO TO 103                                                       SEC  121
 102  CONTINUE                                                        SEC  122
      XSQYSQ=DSQRT(X**2 + Y**2)                                       SEC  123
      IF (Z) 24,25,24                                                 SEC  124
 25   THETA=PIDIV2                                                    SEC  125
      GO TO 26                                                        SEC  126
 24   U=XSQYSQ/Z                                                      SEC  127
      THETA=DATAN(U)                                                  SEC  128
      IF (Z) 44,26,26                                                 SEC  129
 44   THETA=PI + THETA                                                SEC  130
 26   CONTINUE                                                        SEC  131
      CALL ANGLE(X,Y,XLMDA)                                           SEC  132
C     COMPUTE THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION AT POINTSEC  133
      CALL DENSTY (R,THETA,XLMDA,NDEN,REFDEN,DEN)                     SEC  134
 103  CONTINUE                                                        SEC  135
C     PUT THE RIGHT SYMBOL/NUMBER IN XMAP(K)/YMAP(K)                  SEC  136
      XS=(DEN/SCALE) + C.5DC                                          SEC  137
      JNUM=SYMBL + XS                                                 SEC  138
      IF (JNUM .LE. 1) JNUM=1                                         SEC  139
      IF (JNUM .GE. MAXSYM) JNUM=MAXSYM                               SEC  140
 29   XMAP(K)=ALPHA(JNUM)                                             SEC  141
      YMAP(K) = BETA(JNUM)                                            SEC  142
 3    CONTINUE                                                        SEC  143
C     PRINT THE LINE                                                  SEC  144
      WRITE (6,14) (XMAP(K), K=1,121)                                 SEC  145
 14   FORMAT (5X,121A1)                                               SEC  146
      WRITE(10,100)(YMAP(K), K=1,121)                                 SEC  147
 100  FORMAT (121I2)                                                  SEC  148
C
C     RESET THE LINE                                                  SEC  149
      DO 15 K=KMIN,KMAX                                               SEC  150
      XMAP(K)=ALPHA(23)                                               SEC  151
      YMAP(K) = BETA(11)                                              SEC  152
 15   CONTINUE                                                        SEC  153
C
 2    CONTINUE                                                        SEC  154
      XLAT=PHI*(180.0D0/PI)                                           SEC  155
C     PRINT LATITUDE OF EACH SECTION                                  SEC  156
      WRITE (6,30) XLAT                                               SEC  157
 30   FORMAT (///,90X,'LATITUDE=',F9.4,1X,'DEGREES')                  SEC  158
 10   CONTINUE                                                        SEC  159
      RETURN                                                          SEC  160
      END                                                             SEC  161
      SUBROUTINE SLICE (PHI1,XLMDA1,PHI2,XLMDA2,TOLERD,NRAD)          SLI    1
C
C
C        *SLICE*                                                      SLI    2
C
C     THIS SUBROUTINE COMPUTES THE RELATIVE DENSITY/DENSITY/DENSITY   SLI    3
C VARIATION ON A PLANE WHICH PASSES THROUGH THE CENTER OF THE EARTH.   SLI    4
C
C     THE INTERSECTION OF THE PLANE WITH THE EARTH IS CALLED A SLICE. SLI    5
C
C     THE SLICE IS ORIENTED SO AS TO CONTAIN THE TWO POINTS           SLI    6
C (PHI1,XLMDA1) AND (PHI2,XLMDA2). THE LINE WHICH FORMS THE           SLI    7
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C INTERSECTION OF THE SLICE WITH THE EQUATOR RUNS HORIZONTALLY ACROSS   SLI    8
C THE PAGE (PHOTO). WE ARE LOOKING DOWN ON THE SLICE FROM THE NORTHERN  SLI    9
C HEMISPHERE.                                                           SLI   10
C
C
C         ACTATION                                                      SLI   11
C
C     PHI1   = LATITUDE OF FIRST POINT IN DEGREES                       SLI   12
C     XLMDA1 = LONGITUDE OF FIRST POINT IN DEGREES                      SLI   13
C     PHI2   = LATITUDE OF SECOND POINT IN DEGREES                      SLI   14
C     XLMDA2 = LONGITUDE OF SECOND POINT IN DEGREES                     SLI   15
C     TOLERD = TOLERANCE LIMIT IN DEGREES, BELOW WHICH A SMALL          SLI   16
C              DIFFERENCE IN LATITUDE OR LONGITUDE OF THE TWO POINTS    SLI   17
C              IS SET EQUAL TO ZERO TO AVOID SINGULARITIES              SLI   18
C     NRAD   = RADIUS OF SLICE IN HORIZONTAL SPACES ACROSS THE PAGE     SLI   19
C              (PHOTO)                                                  SLI   20
C
C
C     SUBROUTINES CALLED:                                               SLI   21
C
C      1. ANGLE                                                         SLI   22
C      2. CIRC                                                          SLI   23
C      3. DENSTY                                                        SLI   24
C      4. VCG                                                           SLI   25
C
C
C     NOTES                                                             SLI   26
C
C      1. XLMDA2 .GT. XLMDA1.                                           SLI   27
C      2. NRAD .LE. 60.                                                 SLI   28
C      3. SUBROUTINE OUTPUTS CARDS FOR CALCOMP PROGRAM.                 SLI   29
C
C
C     SAMPLE INPUT DATA   (COLUMN 1 OF INPUT STARTS IN COLUMN 3 HERE)   SLI   30
C
C SUBNME                                    (FORMAT: A6)                SLI   31
C SLICE                                                                 SLI   32
C
C   (COMENT(J), J=1,14)                     (FORMAT: 13A6,A2)           SLI   33
C SLICE RUNS DOWN THE HAWAIIAN CHAIN FROM MIDWAY TO BIG ISLAND          SLI   34
C
C  PHI1      XLMDA1      PHI2      XLMDA2     TOLERD      NRAD           SLI   35
C                                                  (FORMAT: 5F10.5,I5)  SLI   36
C 28.11     183.35     19.24      206.59     0.0001       60            SLI   37
C
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                          SLI   38
      INTEGER*2 TMAP(121), BETA(11)                                     SLI   39
      DIMENSION ALPHA(23),LCWHI(205,2)                                  SLI   40
      DIMENSION XMAP(121)                                               SLI   41
      DIMENSION COMENT(14)                                              SLI   42
      COMMON/BLKA/XMAP                                                  SLI   43
      COMMON/BLKC/F,PI,PI2,PIOV2,SCALE,NPHOTO,MAXSYM                    SLI   44
      COMMON/BLKD/ALPHA,LCWHI                                           SLI   45
      COMMON/BLKG/LMIN,LMAX,LLOW,LUP                                    SLI   46
      COMMON/BLKH/RADAVG,FCCRE,RLOWER,RUPPER                            SLI   47
      COMMON/BLKI/COMENT                                                SLI   48
      COMMON/BLKJ/NDEN,REFDEN                                           SLI   49
      COMMON/BLKT/BETA                                                  SLI   50
C
C   PRINT INPUT DATA                                                    SLI   51
      WRITE (6,16)                                                      SLI   52
      WRITE (6,300)                                                     SLI   53
  300 FORMAT (///,10X,'SUBROUTINE CALLED: SLICE',///)                   SLI   54
      WRITE (6,311) (COMENT(J), J=1,14)                                 SLI   55
  311 FORMAT (10X,13A6,A2,///)                                          SLI   56
      WRITE (6,47) PHI1,XLMDA1                                          SLI   57
   47 FORMAT (3X,'FIRST GREAT CIRCLE POINT :',5X,'LATITUDE=',1X,F10.5,  SLI   58
     . 1X,'DEGREES',10X,'LONGITUDE=',1X,F10.5,1X,'DEGREES',//)          SLI   59
      WRITE (6,46) PHI2,XLMDA2                                          SLI   60
   46 FORMAT (3X,'SECOND GREAT CIRCLE POINT:',5X,'LATITUDE=',1X,F10.5,  SLI   61
     . 1X,'DEGREES',10X,'LONGITUDE=',1X,F10.5,1X,'DEGREES',//)          SLI   62
C   CONVERT ANGLES FROM DEGREES TO RADIANS                              SLI   63
      PHI1=PHI1*F                                                       SLI   64
      PHI2=PHI2*F                                                       SLI   65
      XLMDA1=XLMDA1*F                                                   SLI   66
      XLMDA2=XLMDA2*F                                                   SLI   67
      TOLER=TOLERD*F                                                    SLI   68
C   FIND XXI, OMEGA, COSXI, SINXI, COSCMG, SINCMG                       SLI   69
      TOLPHI=DSQRT(PHI1**2 + PHI2**2)                                   SLI   70
C   IS THE GREAT CIRCLE THE EQUATOR?                                    SLI   71
      IF (TOLPHI - TOLER) 79,80,80                                      SLI   72
   79 XXI=0.000                                                         SLI   73
      COSXI=1.000                                                       SLI   74
      SINXI=0.000                                                       SLI   75
      OMEGA=0.000                                                       SLI   76
      COSCMG=1.000                                                      SLI   77
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      SINCMG=0.0D0                                                      SLI   78
      GO TO 81                                                          SLI   79
 80   TCLLAM=CABS(XLMDA2 - XLMDA1)                                      SLI   80
C   IS THE GREAT CIRCLE A MERIDIAN?                                     SLI   81
      IF (TCLLAM - TCLER) 82,83,83                                      SLI   82
 82   XXI=PIDIV2                                                        SLI   83
      CCSXI=0.0D0                                                       SLI   84
      SINXI=1.0D0                                                       SLI   85
      OMEGA=XLMDA1                                                      SLI   86
      CCSCMG=DCOS(OMEGA)                                                SLI   87
      SINCMG=DSIN(OMEGA)                                                SLI   88
      GO TO 81                                                          SLI   89
 83   CONTINUE                                                          SLI   90
      TANCMG=((DSIN(XLMDA1))*(DTAN(PHI2)) - (DSIN(XLMDA2))*(DTAN(PHI1)))SLI   91
     ./((DCOS(XLMDA1))*(DTAN(PHI2)) - (DCOS(XLMDA2))*(DTAN(PHI1)))      SLI   92
      OMEGA=DATAN(TANCMG)                                               SLI   93
      TANXXI=(DTAN(PHI2))/(DSIN(XLMDA2 - OMEGA))                        SLI   94
      IF (TANXXI) 52,52,53                                              SLI   95
 52   OMEGA=OMEGA + PI                                                  SLI   96
      TANXXI=-TANXXI                                                    SLI   97
 53   CONTINUE                                                          SLI   98
      XXI=DATAN(TANXXI)                                                 SLI   99
      IF (OMEGA) 55,54,54                                               SLI  100
 55   OMEGA=OMEGA + PI2                                                 SLI  101
 54   CONTINUE                                                          SLI  102
      XXID=XXI/F                                                        SLI  103
      OMEGAD=OMEGA/F                                                    SLI  104
C   PRINT XXI AND OMEGA IN DEGREES                                      SLI  105
C   XXI = ANGLE OF GREAT CIRCLE WITH EQUATOR                            SLI  106
C   OMEGA = LONGITUDE OF ASCENDING NODE OF GREAT CIRCLE, MEASURED       SLI  107
C   EASTWARD FROM GREENWICH                                             SLI  108
      WRITE (6,301) XXID                                                SLI  109
 301  FORMAT (10X,'XXI =',1X,F10.5,1X,'DEGREES',10X,'(INCLINATION TO EQUSLI  110
     .ATOR)',//)                                                        SLI  111
      WRITE (6,303) OMEGAD                                              SLI  112
 303  FORMAT (10X,'OMEGA =',1X,F10.5,1X,'DEGREES',10X,'(NODE MEASURED EASLI  113
     .T FROM GREENWICH)',///)                                           SLI  114
C   PRINT NRAD                                                          SLI  115
      WRITE (6,302) NRAD                                                SLI  116
 302  FORMAT (10X,'NRAD =',1X,I4,10X,'(RADIUS OF SLICE IN HORIZONTAL SPASLI  117
     .CES)',//)                                                         SLI  118
C                                                                       SLI  119
      CCSXI=DCOS(XXI)                                                   SLI  120
      SINXI=DSIN(XXI)                                                   SLI  121
      CCSCMG=DCOS(OMEGA)                                                SLI  122
      SINCMG=DSIN(OMEGA)                                                SLI  123
 81   CONTINUE                                                          SLI  124
C                                                                       SLI  125
C                                                                       SLI  126
C                                                                       SLI  127
C     COMPUTE CALCOMP PLOTTER DATA FOR PLOTTING TOPOGRAPHY OF SLICE     SLI  128
C     AND GREAT CIRCLE ON VAN DER GRINTEN MAP                           SLI  129
C     RADMAP = RADIUS OF VAN DER GRINTEN MAP IN INCHES                  SLI  130
      RADMAP=10.187500                                                  SLI  131
C     CONVER = INCH TO KM RATIO USED IN TOPOGRAPHY PLOT                 SLI  132
      CONVER=0.100                                                      SLI  133
      RADSEC=NRAD                                                       SLI  134
      RCINCH=RADSEC*(0.1D0)                                             SLI  135
      RINCH=RCINCH + 1.0D0                                              SLI  136
      NDEG=1                                                            SLI  137
      WRITE (6,208)                                                     SLI  138
 208  FORMAT (//////,10X,'CALCOMP PLOT DATA',//)                        SLI  139
      WRITE (6,204) RADMAP                                              SLI  140
 204  FORMAT (12X,'RADIUS OF VAN DER GRINTEN MAP =',F7.3,1X,'INCHES')   SLI  141
      WRITE (6,205) CONVER                                              SLI  142
 205  FORMAT (//,12X,'INCHES PER KM OF TOPO HEIGHT =',F10.5)            SLI  143
      WRITE (6,16)                                                      SLI  144
      WRITE (6,206)                                                     SLI  145
 206  FORMAT (2X,'K',7X,'PSI',7X,'LATITUDE',4X,'LONGITUDE',2X,'TOPO HEIGSLI  146
     .HT',3X,'XGRID',7X,'YGRID',10X,'XH',10X,'YH')                      SLI  147
      WRITE (6,207)                                                     SLI  148
 207  FORMAT (8X,'(DEGREES)',2X,'(DEGREES)',3X,'(DEGREES)',5X,'(KM)',   SLI  149
     . 6X,'(INCHES)',4X,'(INCHES)',5X,'(INCHES)',4X,'(INCHES)',/)       SLI  150
      DO 201 K=1,360                                                    SLI  151
      PSID=K - 1                                                        SLI  152
      PSI=PSID*F                                                        SLI  153
      CCSPSI=DCOS(PSI)                                                  SLI  154
      SINPSI=DSIN(PSI)                                                  SLI  155
      X=CCSPSI*COSOMG - CCSXI*SINOMG*SINPSI                             SLI  156
      Y=CCSPSI*SINCMG + CCSXI*COSOMG*SINPSI                             SLI  157
      Z=SINXI*SINPSI                                                    SLI  158
      XSQYSQ=DSQRT(X**2 + Y**2)                                         SLI  159
      IF (XSQYSQ) 66,67,66                                              SLI  160
 67   PHID=PIDIV2/F                                                     SLI  161
      THETA=0.0D0                                                       SLI  162
      IF (Z) 84,85,85                                                   SLI  163
 84   PHID=-PIDIV2/F                                                    SLI  164
      THETA=PI                                                          SLI  165
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 85   CONTINUE                                                          SLI  162
      GO TO 66                                                          SLI  163
 66   U=Z/XSQYSQ                                                        SLI  164
      PHI=ATAN(U)                                                       SLI  165
      THETA=PIDIV2 - PHI                                                SLI  166
      PHIC=PHI/F                                                        SLI  167
 68   CONTINUE                                                          SLI  168
      CALL ANGLE (X,Y,XLMDA)                                            SLI  169
      XLMDAC=XLMDA/F                                                    SLI  170
      IF (XLMDAC) 73,74,74                                              SLI  171
 73   XLMDAC=XLMDAC + 360.0D0                                           SLI  172
 74   CONTINUE                                                          SLI  173
      CALL TOPOGR (THETA,XLMDA,H)                                       SLI  174
      H=H*CONVER                                                        SLI  175
      CALL VOG (PHIC,XLMDAD,RADMAP,NDEG,XG,YG)                          SLI  176
      XH=(RINCH + H)*COSF$I                                             SLI  177
      YH=(RINCH + H)*SINF$I                                             SLI  178
 202  FORMAT (1X,I4,6(2X,F10.2),3X,F10.3,2X,F10.3)                      SLI  179
      WRITE (6,202) K,PSIL,PHID,XLMDAD,H,XG,YG,XH,YH                    SLI  180
      WRITE (7,203) K,XG,YG,XH,YH                                       SLI  181
 203  FORMAT (I5,4F10.3)                                                SLI  182
 201  CONTINUE                                                          SLI  183
C
C
C
C
C    FIND PICOLE OF SYMBOL/CCLOR RANGE                                 SLI  184
       SYMMAX=MAXSYM                                                    SLI  185
       SYMBL=SYMMAX/2.0D0 + 0.5D0                                       SLI  186
C
C    COMPUTE NUMBER OF HORIZONTAL LINES IN MAP                         SLI  187
       NRDSEC=NRAD                                                      SLI  188
       RADSEC=NRAD                                                      SLI  189
       NRY=4*NRDSEC/5                                                   SLI  190
       IF (NPHOTO .EQ. 1) NRY=NRDSEC                                    SLI  191
       NY=2*NRY + 1                                                     SLI  192
       NRY1=NRY + 1                                                     SLI  193
       RY1=NRY1                                                         SLI  194
C    FIND LEFT AND RIGHT LIMITS OF MAP BY CALLING CIRC                 SLI  195
       CALL CIRC(NRDSEC)                                                SLI  196
C
       DO 10 NUMMAP=1,1                                                 SLI  197
C
C    INITIALIZE LINE VALUES                                            SLI  198
C    XMAP IS FOR PRINT-OUT PICTURE                                     SLI  199
C    TMAP IS FOR DICOMED PHOTO                                         SLI  200
       DO 4 K=1,121                                                     SLI  201
       TMAP(K) = BETA(11)                                               SLI  202
  4    XMAP(K)=ALPHA(23)                                                SLI  203
C
C    SPACE DOWN THE PAGE                                               SLI  204
       WRITE (6,16)                                                     SLI  205
 16    FORMAT (1H1)                                                     SLI  206
       NSPACE=120 - NRY                                                 SLI  207
       DO 17 KK=1,NSPACE                                                SLI  208
 17    WRITE (6,18) ALPHA(23)                                           SLI  209
 18    FORMAT (10X,1A1)                                                 SLI  210
C
C    FIND THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION ON EACH  SLI  211
C    HORIZONTAL LINE                                                   SLI  212
       DO 2 LP=1,NY                                                     SLI  213
       LZ=NY -LP + 1                                                    SLI  214
       FLZ=LZ                                                           SLI  215
       KMIN=LOWHI(LP,1)                                                 SLI  216
       KMAX=LOWHI(LP,2)                                                 SLI  217
C
       DO 3 K=KMIN,KMAX                                                 SLI  218
C    FIND THE X,Y,Z COORDINATES OF EACH POINT ON THE LINE              SLI  219
       FK=K                                                             SLI  220
       XP=(FK - 61.000)*(RUPPER/RADSEC)                                 SLI  221
       STRECH=5.000/4.000                                               SLI  222
       IF (NPHOTO .EQ. 1) STRECH=1.000                                  SLI  223
       YP=(FLZ - RY1)*(STRECH*RUPPER)/RADSEC                            SLI  224
       X=(COSOMG)*XP - (COSXI*SINOMG)*YP                                SLI  225
       Y=(SINOMG)*XP + (COSXI*COSOMG)*YP                                SLI  226
       Z=(SINXI)*YP                                                     SLI  227
C    FIND THE SPHERICAL POLAR COORDINATES OF POINT                     SLI  228
       R=DSQRT(XP**2 + YP**2)                                           SLI  229
C    IS THE POINT IN THE CORE?                                         SLI  230
       IF (R - RCORE) 28,27,27                                          SLI  231
 28    JNUM=22                                                          SLI  232
C      8 IS USED FOR CORE                                              SLI  233
       GO TO 29                                                         SLI  234
 27    CONTINUE                                                         SLI  235
C    IS THE POINT BELOW RLOWER?                                        SLI  236
       IF (R - RLOWER) 101,102,102                                      SLI  237
 101   DEN=0.000                                                        SLI  238
       GO TO 103                                                        SLI  239
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 102  CONTINUE                                                          SLI  240
      XSQYSQ=ESQRT(X**2 + Y**2)                                         SLI  241
      IF (Z) 24,25,24                                                   SLI  242
 25   THETA=PIDIV2                                                      SLI  243
      GO TO 26                                                          SLI  244
 24   U=XSQYSQ/Z                                                        SLI  245
      THETA=DATAN(U)                                                    SLI  246
      IF (Z) 44,26,26                                                   SLI  247
 44   THETA=PI + THETA                                                  SLI  248
 26   CONTINUE                                                          SLI  249
      CALL ANGLE(X,Y,XLPDA)                                             SLI  250
C   COMPUTE THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION AT POINTSLI  251
      CALL DENSTY (R,THETA,XLPDA,NDEN,REFDEN,DEN)                       SLI  252
 103  CONTINUE                                                          SLI  253
C   PUT THE RIGHT SYMBOL/NUMBER IN XMAP(K)/YMAP(K)                    SLI  254
      XS=(DEN/SCALE) + 0.5DO                                            SLI  255
      JNUM=SYMBL + XS                                                   SLI  256
      IF (JNUM .LE. 1) JNUM=1                                           SLI  257
      IF (JNUM .GE. MAXSYM) JNUM=MAXSYM                                 SLI  258
 29   XMAP(K)=ALPHA(JNUM)                                               SLI  259
      YMAP(K) = BETA(JNUM)                                              SLI  260
 3    CONTINUE                                                          SLI  261
C
C   PRINT THE LINE                                                    SLI  262
      WRITE (6,14) (XMAP(K), K=1,121)                                   SLI  263
 14   FORMAT (5X,121A1)                                                 SLI  264
C     WRITE (10,100)(YMAP(K), K=1,121)                                  SLI  265
C 100 FORMAT (12I12)                                                    SLI  266
C
C   RESET THE LINE                                                    SLI  267
      DO 15 K=KMIN,KMAX                                                 SLI  268
      XMAP(K)=ALPHA(23)                                                 SLI  269
      YMAP(K) = BETA(11)                                                SLI  270
 15   CONTINUE                                                          SLI  271
 2    CONTINUE                                                          SLI  272
C
 10   CONTINUE                                                          SLI  273
      RETURN                                                            SLI  274
      END                                                               SLI  275
      SUBROUTINE VANDER (RKM,HMAP,WMAP,NRAD)                            VAN    1
C
C        *VANDER*                                                       VAN    2
C
C     THIS SUBROUTINE COMPUTES THE RELATIVE DENSITY, DENSITY, OR       VAN    3
C DENSITY VARIATION ON A SURFACE OF CHOSEN RADIUS USING THE VAN DER     VAN    4
C GRINTEN PROJECTION.                                                  VAN    5
C
C     IT DIVIDES THE MAP INTO TWO HEMISPHERES TO MAKE THE MAP BIG      VAN    6
C ENOUGH TO OVERLAY ON PAUL LOWMAN'S TECTONIC ACTIVITY MAP.            VAN    7
C
C
C     NOTATION                                                         VAN    8
C
C     RKM    = RADIAL DISTANCE OF MAP SURFACE IN KILOMETERS            VAN    9
C     HMAP   = TOTAL HEIGHT OF OVERLAY MAP IN CENTIMETERS              VAN   10
C     WMAP   = TOTAL WIDTH OF OVERLAY MAP IN CENTIMETERS               VAN   11
C     NRAD   = RADIUS OF MAP IN HORIZONTAL SPACES ACROSS THE PAGE      VAN   12
C              (PHOTO)                                                 VAN   13
C
C
C     SUBROUTINES CALLED:                                              VAN   14
C
C      1. CIRC                                                         VAN   15
C      2. CUBIC                                                        VAN   16
C      3. DENSTY                                                       VAN   17
C      4. QUADRC                                                       VAN   18
C
C
C     NOTES                                                            VAN   19
C
C      1. NRAD .LE. 102.                                               VAN   20
C      2. WMAP .LE. 52 CM.                                             VAN   21
C
C
C     SAMPLE INPUT DATA   (COLUMN 1 OF INPUT STARTS IN COLUMN 3 HERE)  VAN   22
C
C SUBNME                                (FORMAT: A6)                   VAN   23
C VANDER                                                               VAN   24
C
C  (COMMENT(J), J=1,14)                 (FORMAT: 13A6,A2)              VAN   25
C SURFACE MAP                                                          VAN   26
C
C  NRAD    RKM       HMAP       WMAP    (FORMAT: I5,3F10.5)           VAN   27
C   102  6371.0     38.2       52.0                                   VAN   28
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                         VAN   29
      INTEGER*2 YMAP(121), BETA(11)                                    VAN   30
```

```
      DIMENSION ALPHA(23),LOWHI(205,2)                                  VAN   31
      DIMENSION XMAP(121)                                               VAN   32
      DIMENSION COMENT(14)                                              VAN   33
      COMMON/BLKA/XMAP                                                  VAN   34
      COMMON/BLKC/F,PI,PI2,PIBY2,SCALE,NPHOTO,MAXSYM                    VAN   35
      COMMON/BLKD/ALPHA,LOWHI                                           VAN   36
      COMMON/BLKG/LPMIN,LMAX,LLOW,LUP                                   VAN   37
      COMMON/BLKH/RADAVG,RCORE,RLOWER,RUPPER                            VAN   38
      COMMON/BLKI/COMENT                                                VAN   39
      COMMON/BLKJ/NDEN,REFDEN                                           VAN   40
      COMMON/BLKT/BETA                                                  VAN   41
C
C   PRINT INPUT DATA                                                    VAN   42
      WRITE (6,16)                                                      VAN   43
      WRITE (6,300)                                                     VAN   44
  300 FORMAT (///,10X,'SUBROUTINE CALLED: VANDER',///)                  VAN   45
      WRITE (6,311) (COMENT(J), J=1,14)                                 VAN   46
  311 FORMAT (10X,13A6,A2,///)                                          VAN   47
      WRITE (6,301) RKM                                                 VAN   48
  301 FORMAT (10X,'RKM =',1X,F10.3,1X,'KM',10X,'(RADIAL DISTANCE OF SURFVAN   49
     ,ACE)',///)                                                        VAN   50
      WRITE (6,302) NRAD                                                VAN   51
  302 FORMAT (10X,'NRAD =',1X,I4,10X,'(RADIUS OF MAP IN HORIZONTAL SPACEVAN   52
     ,S)',///)                                                          VAN   53
C
      R=RKM/RADAVG                                                      VAN   54
C
C   FIND MIDDLE OF SYMBOL/COLOR RANGE                                   VAN   55
      SYMMAX=MAXSYM                                                     VAN   56
      SYMBL=SYMMAX/2.000 + 0.500                                        VAN   57
C
C   COMPUTE NUMBER OF HORIZONTAL LINES IN MAP                           VAN   58
      NRDSEC=NRAD                                                       VAN   59
      RADSEC=NRAD                                                       VAN   60
      NRY=4*NRDSEC/5                                                    VAN   61
      IF (NPHOTO .EQ. 1) NRY=NRDSEC                                     VAN   62
      NY=2*NRY + 1                                                      VAN   63
      NRY1=NRY + 1                                                      VAN   64
      RY1=NRY1                                                          VAN   65
C   FIND LEFT AND RIGHT LIMITS OF MAP BY CALLING CIRC                   VAN   66
      CALL CIRC(NRDSEC)                                                 VAN   67
C
      DO 10 NUMMAP=1,1                                                  VAN   68
C
C   DO WESTERN HEMISPHERE, THEN EASTERN HEMISPHERE                      VAN   69
      DO 10 NHEMIS=1,2                                                  VAN   70
C   INITIALIZE LINE VALUES                                              VAN   71
C   XMAP IS FOR PRINT-OUT PICTURE                                       VAN   72
C   TMAP IS FOR DICOMED PHOTO                                           VAN   73
      DO 4 K=1,121                                                      VAN   74
      TMAP(K) = BETA(11)                                                VAN   75
    4 XMAP(K)=ALPHA(23)                                                 VAN   76
C
      WRITE (6,16)                                                      VAN   77
   16 FORMAT (1H1)                                                      VAN   78
      NV=(RY1 - 1.000)*NMAP/NMAP                                        VAN   79
      LPMIN=NRY - NV                                                    VAN   80
      LPMAX=NY - LPMIN + 1                                              VAN   81
C   FIND THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION ON EACH    VAN   82
C   HORIZONTAL LINE                                                     VAN   83
      DO 2 LP=LPMIN,LPMAX                                               VAN   84
      IF (NHEMIS .EQ. 2) GO TO 51                                       VAN   85
      TERM=0.000                                                        VAN   86
      KMIN=1                                                            VAN   87
      KMAX=LOWHI(LP,2) - 40                                             VAN   88
      GO TO 52                                                          VAN   89
   51 TERM=RADSEC                                                       VAN   90
      KMIN=LOWHI(LP,1) - 40 + NRDSEC                                    VAN   91
      KMAX=NRDSEC                                                       VAN   92
   52 CONTINUE                                                          VAN   93
      LZ=NY -LP + 1                                                     VAN   94
      FLZ=LZ                                                            VAN   95
C
      DO 3 K=KMIN,KMAX                                                  VAN   96
C   FIND THE X,Y,Z COORDINATES OF EACH POINT ON THE LINE                VAN   97
      FK=K                                                              VAN   98
      X=FK - 1.000 - TERM                                               VAN   99
      STRECH=5.000/4.000                                                VAN  100
      IF (NPHOTO .EQ. 1) STRECH=1.000                                   VAN  101
      Y=(FLZ - RY1)*STRECH                                              VAN  102
C   FIND THE SPHERICAL POLAR COORDINATES OF POINT                       VAN  103
      CALL CUBIC(X,Y,RADSEC,THETA)                                      VAN  104
      CALL QUADRC(X,Y,RADSEC,XLMDA)                                     VAN  105
C   COMPUTE THE RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION AT POINTVAN  106
      CALL DENSTY (R,THETA,XLMDA,NDEN,REFDEN,DEN)                       VAN  107
C   PUT THE RIGHT SYMBOL/NUMBER IN XMAP(K)/TMAP(K)                      VAN  108
      XS=(DEN/SCALE) + 0.500                                            VAN  109
      JNUM=SYMBL + XS                                                   VAN  110
```

```
      IF (JNUM .LE. 1) JNUM=1                                          VAN  111
      IF (JNUM .GE. MAXSYM) JNUM=MAXSYM                                VAN  112
 29   XMAP(K)=ALPHA(JNUM)                                              VAN  113
      YMAP(K) = BETA(JNUM)                                             VAN  114
 3    CONTINUE                                                         VAN  115
C   PRINT THE LINE                                                    VAN  116
      WRITE (6,14) (XMAP(K), K=1,121)                                  VAN  117
 14   FORMAT (5X,121A1)                                                VAN  118
C     WRITE (10,100)(YMAP(K), K=1,121)                                 VAN  119
C 100 FORMAT (12112)                                                   VAN  120
C                                                                      VAN  121
C   RESET THE LINE                                                     VAN  122
      DO 15 K=KMIN,KMAX                                                VAN  123
      XMAP(K)=ALPHA(23)                                                VAN  124
      YMAP(K) = BETA(11)                                               VAN  125
 15   CONTINUE                                                         VAN  126
C                                                                      VAN  127
 2    CONTINUE                                                         VAN  128
C                                                                      VAN  129
 10   CONTINUE                                                         VAN  130
      RETURN                                                           VAN  131
      END                                                              VAN  132
      SUBROUTINE DENSTY (F,THETA,XLMDA,NDEN,REFDEN,DEN)                DEN    1
C                                                                      DEN    2
C                                                                      DEN    3
C     THIS SUBROUTINE COMPUTES THE RELATIVE DENSITY, DENSITY, OR       DEN    4
C DENSITY VARIATION AT A POINT INSIDE THE EARTH.                       DEN    5
C                                                                      DEN    6
C                                                                      DEN    7
C         NOTATION                                                     DEN    8
C                                                                      DEN    9
C     R       = RADIAL DISTANCE OF POINT FROM THE CENTER OF THE EARTH, DEN   10
C               NORMALIZED TO THE EARTH'S RADIUS                       DEN   11
C     THETA   = COLATITUDE OF POINT IN RADIANS                         DEN   12
C     XLMDA   = ANGLE OF POINT WITH THE X-AXIS, LYING IN THE X-Y PLANE,DEN   13
C               MEASURED IN RADIANS                                    DEN   14
C     DEN     = RELATIVE DENSITY, DENSITY, OR DENSITY VARIATION AT THE DEN   15
C               POINT                                                  DEN   16
C     NDEN    = 0 FOR RELATIVE DENSITY, =1 FOR ACTUAL DENSITY,         DEN   17
C               =2 FOR DENSITY VARIATION                               DEN   18
C                                                                      DEN   19
C                                                                      DEN   20
C     SUBROUTINES CALLED:                                              DEN   21
C                                                                      DEN   22
C      1. LGENDR                                                       DEN   23
C      2. CZIEWN (IF NDEN=1 OR NDEN=2)                                 DEN   24
C                                                                      DEN   25
C                                                                      DEN   26
      IMPLICIT REAL*8(A-H,O-Z)                                         DEN   27
      DIMENSION CLM(36,37,2),COE(36)                                   DEN   28
      DIMENSION PBAR(703)                                              DEN   29
      COMMON/BLKB/CLM,CCE                                              DEN   30
      COMMON/BLKC/F,PI,PI2,PIOIV2,SCALE,NPHOTO,MAXSYM                  DEN   31
      COMMON/BLKG/LMIN,LMAX,LLOW,LUP                                   DEN   32
      COMMON/BLKH/RADAVG,RCORE,RLOWER,RUPPER                           DEN   33
      COMMON/BLKF/PBAR                                                 DEN   34
C   CHANGE VARIABLES FROM THETA TO PHI                                 DEN   35
      PHI=PIOIV2 - THETA                                               DEN   36
C   COMPUTE LEGENDRE POLYNOMIALS                                       DEN   37
      CALL LGENDR(PHI,LMAX)                                            DEN   38
C   COMPUTE RELATIVE DENSITY                                           DEN   39
      SUM=0.000                                                        DEN   40
      DO 5 L=LMIN,LMAX                                                 DEN   41
      RL=R**L                                                          DEN   42
      MAX=L + 1                                                        DEN   43
      DO 5 M1=1,MAX                                                    DEN   44
      XM=M1 - 1                                                        DEN   45
      ARG=XM*XLMDA                                                     DEN   46
      SS=DSIN(ARG)                                                     DEN   47
      CC=DCOS(ARG)                                                     DEN   48
      IND=M1 + L*(L+1)/2                                               DEN   49
      SUM=SUM + (CLM(L,M1,1)*CC + CLM(L,M1,2)*SS)*(PBAR(IND))*RL       DEN   50
 5    CONTINUE                                                         DEN   51
      DEN=SUM                                                          DEN   52
C   SEE IF ACTUAL DENSITY IS WANTED                                    DEN   53
      IF (NDEN .EQ. 1) GO TO 7                                         DEN   54
C   SEE IF DENSITY VARIATION IS WANTED                                 DEN   55
      IF (NDEN .EQ. 2) GO TO 9                                         DEN   56
      GO TO 8                                                          DEN   57
 7    CONTINUE                                                         DEN   58
      CALL CZIEWN (R,DENOZI)                                           DEN   59
      DEN=CENOZI*(1.000 + DEN) - REFDEN                                DEN   60
      GO TO 8                                                          DEN   61
 9    CONTINUE                                                         DEN   62
      CALL CZIEWN (R,DENOZI)                                           DEN   63
      DEN=CENOZI*DEN                                                   DEN   64
 8    CONTINUE                                                         DEN   65
      RETURN                                                           DEN   66
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      END                                                               DEN   57
      SUBROUTINE ANGLE(X,Y,XLMDA)                                       ANG    1
C
C
C     THIS SUBROUTINE COMPUTES THE ANGLE WITH THE X-AXIS FROM THE (X,Y) ANG    2
C COORDINATES OF A POINT.                                               ANG    3
C
C        NOTATION                                                       ANG    4
C
C     X       = X-COORDINATE OF POINT                                   ANG    5
C     Y       = Y-COORDINATE OF POINT                                   ANG    6
C     XLMDA   = ANGLE WITH X-AXIS                                       ANG    7
C
C
C     SUBROUTINES CALLED:                                               ANG    8
C
C         NONE                                                          ANG    9
C
C
C     NOTES                                                             ANG   10
C
C     1. XLMDA IS MEASURED IN RADIANS.                                  ANG   11
C     2. IF X=0 AND Y=0, THEN XLMDA=0.                                  ANG   12
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                          ANG   13
      PI=3.14159265358979310                                            ANG   14
      PIDIV2=PI/2.000                                                   ANG   15
      IF (X) 21,22,23                                                   ANG   16
   21 U=Y/X                                                             ANG   17
      XLMDA=DATAN(U)                                                    ANG   18
      IF (Y) 24,25,24                                                   ANG   19
   24 XLMDA=XLMDA + PI                                                  ANG   20
      GO TO 30                                                          ANG   21
   25 XLMDA=PI                                                          ANG   22
      GO TO 30                                                          ANG   23
   22 CONTINUE                                                          ANG   24
      IF (Y) 27,28,29                                                   ANG   25
   27 XLMDA=-PIDIV2                                                     ANG   26
      GO TO 30                                                          ANG   27
   28 XLMDA=0.000                                                       ANG   28
      GO TO 30                                                          ANG   29
   29 XLMDA=PIDIV2                                                      ANG   30
      GO TO 30                                                          ANG   31
   23 CONTINUE                                                          ANG   32
      IF (Y) 31,32,31                                                   ANG   33
   31 U=Y/X                                                             ANG   34
      XLMDA=DATAN(U)                                                    ANG   35
      GO TO 30                                                          ANG   36
   32 XLMDA=0.000                                                       ANG   37
   30 CONTINUE                                                          ANG   38
      RETURN                                                            ANG   39
      END                                                               ANG   40
      SUBROUTINE LGENDR(PHI,NMAX)                                       LGE    1
C
C
C     THIS SUBROUTINE COMPUTES THE NORMALIZED ASSOCIATED LEGENDRE       LGE    2
C POLYNOMIALS.                                                          LGE    3
C
C        NOTATION                                                       LGE    4
C
C     PHI     = GEOCENTRIC LATITUDE IN RADIANS                          LGE    5
C     NMAX    = MAXIMUM DEGREE AND ORDER OF THE POLYNOMIALS             LGE    6
C     PBAR    = ARRAY IN WHICH THE POLYNOMIALS ARE STORED               LGE    7
C
C
C     SUBROUTINES CALLED:                                               LGE    8
C
C         NONE                                                          LGE    9
C
C
C     NOTES                                                             LGE   10
C
C      1. COMPUTES POLYNOMIALS USING KAULA'S 4*PI NORMALIZATION.        LGE   11
C      2. NMAX IS LESS THAN OR EQUAL TO 180.                            LGE   12
C      3. DIMENSION OF PBAR IS  1 + NMAX*(NMAX+3)/2.                    LGE   13
C      4. POLYNOMIAL OF DEGREE N AND ORDER M IS STORED IN PBAR(INDEX),  LGE   14
C         WHERE INDEX = 1 + M + N*(N+1)/2.                              LGE   15
C      5. SUBROUTINE HAS UNDERFLOWS WHEN PHI IS NEAR THE POLES.         LGE   16
C
C
      IMPLICIT REAL*8 (A-H,O-Z)                                         LGE   17
      LOGICAL NOTIST                                                    LGE   18
      DIMENSION PBAR(703),SCRCOF(361)                                   LGE   19
      COMMON/BLKF/PBAR                                                  LGE   20
      DATA NOTIST/.FALSE./                                              LGE   21
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```
      INDXP(N,M)=1+P*K*(N+1)/2                                          LGE   22
      IF (NCTIST) CO TO 5                                               LGE   23
      NCTIST=.TRUE.                                                     LGE   24
      NSTCP=2*NMAX+1                                                    LGE   25
      IF (NSTCP.GT.361) STOP 6                                          LGE   26
      DO 4 I=1,NSTCP                                                    LGE   27
    4 SQRCOT(I)=DSQRT(DFLOAT(I))                                        LGE   28
    5 SINPHI=DSIN(PHI)                                                  LGE   29
      COSPHI=DCOS(PHI)                                                  LGE   30
      PBAR(INDXP(0,0))=1DC                                              LGE   31
      PBAR(INDXP(1,0))=SQRCOT(3)*SINPHI                                 LGE   32
      PBAR(INDXP(1,1))=SQRCOT(3)*COSPHI                                 LGE   33
      DO 20 N=2,NMAX                                                    LGE   34
      PBAR(INDXP(N,0))=SQRCOT(2*N+1)/DFLOAT(N)*                         LGE   35
     *                 (SQRCOT(2*N-1)*SINPHI*PBAR(INDXP(N-1,0))       LGE   36
     *                -DFLOAT(N-1)*PBAR(INDXP(N-2,0))/SQRCOT(2*N-3))  LGE   37
      T1=SQRCOT(2*N-1)*COSPHI                                           LGE   38
      T2=SQRCOT(2)*T1*PBAR(INDXP(N-1,0))                                LGE   39
      IF (3-N) 8,8,9                                                    LGE   40
    8 T2=T2*SQROOT(N-1)*SQRCOT(N-2)*PBAR(INDXP(N-2,1))/SQRCOT(2*N-3)    LGE   41
    9 PBAR(INDXP(N,1))=SQRCOT(2*N+1)*T2/(SQRCOT(N)*SQRCOT(N+1))         LGE   42
      DO 20 M=2,N                                                       LGE   43
      T2=T1*PBAR(INDXP(M-1,M-1))                                        LGE   44
      IF (M-N+2) 11,11,12                                               LGE   45
   11 T2=T2*SQRCOT(N-M)*SQRCOT(N+M-1)*PBAR(INDXP(N-2,M))/SQRCOT(2*N-3)  LGE   46
   12 PBAR(INDXP(N,M))=SQRCOT(2*N+1)*T2/(SQROOT(N+M)*SQRCOT(N+M-1))     LGE   47
   20 CONTINUE                                                          LGE   48
      RETURN                                                            LGE   49
      END                                                               LGE   50
      SUBROUTINE DZIBWN(R,DENDZI)                                       DZI    1
C
C
C     THIS SUBROUTINE COMPUTES THE SPHERICALLY SYMMETRIC PART OF THE    DZI    2
C DENSITY DISTRIBUTION. IT USES THE AVERAGE STRUCTURE PARAMETRIZED      DZI    3
C EARTH MODEL OF A.M. DZIEWONSKI, ET AL., "PARAMETRICALLY SIMPLE EARTH  DZI    4
C MODELS CONSISTENT WITH GEOPHYSICAL DATA", PHYSICS OF THE EARTH AND     DZI    5
C PLANETARY INTERIORS, VOLUME 10, PP. 12-48, 1975. (SEE ESPECIALLY      DZI    6
C TABLE 1.)                                                             DZI    7
C
C
C         NOTATION                                                      DZI    8
C
C     DENDZI = DENSITY IN GMAMS/CM**3                                   DZI    9
C     R      = RADIAL DISTANCE, NORMALIZED TO THE RADIUS OF THE EARTH   DZI   10
C     F(J)   = RADIAL DISTANCE OF DENSITY DISCONTINUITIES, ALSO        DZI   11
C              NORMALIZED TO THE RADIUS OF THE EARTH                    DZI   12
C
C
C     SUBROUTINES CALLED:                                               DZI   13
C
C         NONE                                                          DZI   14
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                          DZI   15
      DIMENSION F(11)                                                   DZI   16
      COMMON/BLKH/RADAVG,RCORE,RLOWER,RUPPER                            DZI   17
      F(1)=0.000                                                        DZI   18
      F( 2)=1217.100/RADAVG                                             DZI   19
      F( 3)=3485.700/RADAVG                                             DZI   20
      F( 4)=5701.000/RADAVG                                             DZI   21
      F( 5)=5951.000/RADAVG                                             DZI   22
      F( 6)=6151.000/RADAVG                                             DZI   23
      F( 7)=6291.000/RADAVG                                             DZI   24
      F( 8)=6352.000/RADAVG                                             DZI   25
      F( 9)=6357.000/RADAVG                                             DZI   26
      F(10)=6368.000/RADAVG                                             DZI   27
      F(11)=1.000                                                       DZI   28
      IF (R - F(2)) 1,1,2                                               DZI   29
C  REGION 1                                                            DZI   30
    1 DENDZI=13.01219D0 - 8.4529200*(R**2)                              DZI   31
      GO TO 19                                                          DZI   32
    2 CONTINUE                                                          DZI   33
      IF (R - F(3)) 3,3,4                                               DZI   34
C  REGION 2                                                            DZI   35
    3 DENDZI=12.58416D0 - 1.6592000*R - 1.9412800*(R**2) - 7.1121500*(R**DZI   36
     *3)                                                                DZI   37
      GO TO 19                                                          DZI   38
    4 CONTINUE                                                          DZI   39
      IF (R - F(4)) 5,5,6                                               DZI   40
C  REGION 3                                                            DZI   41
    5 DENDZI=6.8143000 - 1.6627300*R - 1.1853100*(R**2)                 DZI   42
      GO TO 19                                                          DZI   43
    6 CONTINUE                                                          DZI   44
      IF (R - F(5)) 7,7,8                                               DZI   45
C  REGION 4                                                            DZI   46
    7 DENDZI=11.11978D0 - 7.8705400*R                                   DZI   47
      GO TO 19                                                          DZI   48
    8 CONTINUE                                                          DZI   49
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      IF (R - F(6)) 9,9,1C                                              DZI   50
C  REGION 5                                                             DZI   51
 9    DENSZI=7.158855DC - 3.855999DC*R                                  DZI   52
      GC TC 19                                                          DZI   53
 1C   CCNTINUE                                                         DZI   54
      IF (R - F(7)) 11,11,12                                            DZI   55
C  REGION 6                                                             DZI   56
 11   DENSZI=7.158855DC - 3.855999DC*R                                  DZI   57
      GC TC 19                                                          DZI   58
 12   CCNTINUE                                                         DZI   59
      IF (R - F(8)) 13,13,14                                            DZI   60
C  REGION 7                                                             DZI   61
 13   DENSZI=7.158855DC - 3.855999DC*R                                  DZI   62
      GC TC 19                                                          DZI   63
 14   CCNTINUE                                                         DZI   64
      IF (R - F(9)) 15,15,16                                            DZI   65
C  REGION 8                                                             DZI   66
 15   DENSZI=2.902CCDC                                                  DZI   67
      GC TC 19                                                          DZI   68
 16   CCNTINUE                                                         DZI   69
      IF (R - F(10)) 17,17,18                                           DZI   70
C  REGION 9                                                             DZI   71
 17   DENSZI=2.802CCDC                                                  DZI   72
      GC TC 19                                                          DZI   73
C  REGION 10                                                            DZI   74
 18   DENSZI=1.030CCDC                                                  DZI   75
 19   CCNTINUE                                                         DZI   76
      RETURN                                                            DZI   77
      END                                                               DZI   78
      SUBROUTINE TCPCGR (THETA,XLMDA,H)                                 TOP    1
C
C
C     THIS SUBROUTINE CCMPUTES THE TOPCGRAPHIC HEIGHT AT A POINT ON     TOP    2
C THE SURFACE OF THE EARTH.                                             TOP    3
C
C
C         NCTATION                                                      TOP    4
C
C     THETA  = COLATITUCE OF POINT IN RADIANS                           TOP    5
C     XLMDA  = ANGLE OF PCINT WITH THE X-AXIS, LYING IN THE X-Y PLANE,  TOP    6
C              MEASURED IN RADIANS                                      TOP    7
C     H      = TOPCGRAPHIC HEIGHT IN KILOMETERS                         TOP    8
C
C
C     SUBRCUTINES CALLED:                                               TOP    9
C
C      1. LGENDR                                                        TOP   10
C
      IMPLICIT REAL*8(A-H,C-Z)                                          TOP   11
      DIMENSION TCPC(36,37,2)                                           TOP   12
      DIMENSION PBAR(703)                                               TOP   13
      CCMMCN/BLKC/PI,PI2,PIDIV2,SCALE,NPHOTO,MAXSYM                     TOP   14
      CCMMCN/BLKP/PBAR                                                  TOP   15
      CCMMCN/BLKQ/LMIN,LMAX,LLOW,LUP                                    TOP   16
      CCMMCN/BLKR/RADAVG,RCORE,RLOWER,RUPPER                            TOP   17
      CCMMCN/BLKS/TCPC                                                  TOP   18
C   CHANGE VARIABLES FRCM THETA TC PHI                                  TOP   19
      PHI=PIDIV2 - THETA                                                TOP   20
C   CCMPUTE LEGENDRE POLYNCMIALS                                        TOP   21
      CALL LGENDR(PHI,LMAX)                                             TOP   22
C   CCMPUTE TCPOGRAPHIC HEIGHT IN KILOMETERS                            TOP   23
      SUM=C.0D0                                                         TOP   24
      DC 5 L=LMIN,LMAX                                                  TOP   25
      MAX=L + 1                                                         TOP   26
      DC 5 M1=1,MAX                                                     TOP   27
      XM=M1 - 1                                                         TOP   28
      ARG=XM*XLMDA                                                      TOP   29
      SS=DSIN(ARG)                                                      TOP   30
      CC=DCOS(ARG)                                                      TOP   31
      IND=M1 + L*(L+1)/2                                                TOP   32
      SUM=SUM + ((TCPC(L,M1,1))*CC + (TCPC(L,M1,2))*SS)*(PBAR(IND))     TOP   33
 5    CCNTINUE                                                          TOP   34
      H=SUM*RADAVG                                                      TOP   35
      RETURN                                                            TOP   36
      END                                                               TOP   37
      SUBRCUTINE CIRC(NRDSEC)                                           CIR    1
C
C
C     THIS SUBRCUTINE CCMPUTES THE SPACES IN WHICH THE CIRCULAR-        CIR    2
C SHAPED MAPS START AND STOP CN A PARTICULAR LINE.                      CIR    3
C
C
C         NCTATION                                                      CIR    4
C
C     NRDSEC = RADIUS OF CIRCLE, MEASURED IN HORIZONTAL SPACES          CIR    5
C     LCWH   = ARRAY IN WHICH THE SPACE WHERE THE MAP STARTS AND STOPS  CIR    6
C              ON A PARTICULAR LINE IS STORED                           CIR    7
```

```
C
C
C     SUBROUTINES CALLED:                                                CIR    8
C
C         ACNE                                                           CIR    9
C
C
C     NOTES                                                              CIR   10
C
C      1. LOWHI(LP,1) STORES THE SPACE NUMBER WHERE THE MAP STARTS ON    CIR   11
C         LINE LP, AND LOWHI(LP,2) WHERE IT STOPS (INCLUSIVE).           CIR   12
C      2. ALL MAPS ARE CENTERED ON SPACE 61.                             CIR   13
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                           CIR   14
      DIMENSION ALPHA(23),LOWHI(205,2)                                   CIR   15
      COMMON/BLK0/F,PI,PI3,PIDIV2,SCALE,NPHOTO,MAXSYM                    CIR   16
      COMMON/BLK0/ALPHA,LOWHI                                            CIR   17
      RADSEC=ARDSEC                                                      CIR   18
      NRY=4*NRDSEC/5                                                     CIR   19
      IF (NPHOTO .EQ. 1) NRY=NRDSEC                                      CIR   20
      NY=2*NRY + 1                                                       CIR   21
      NRY1=NRY + 1                                                       CIR   22
      RY1=NRY1                                                           CIR   23
      DO 11 LP=1,NRY1                                                    CIR   24
      IF (LP .EQ. NRY1) GO TO 12                                         CIR   25
      YY=NRY1 - LP                                                       CIR   26
      STRECH=5.000/4.000                                                 CIR   27
      IF (NPHOTO .EQ. 1) STRECH=1.000                                    CIR   28
      S=RADSEC**2 - (STRECH*YY)**2                                       CIR   29
      XX=DSQRT(S)                                                        CIR   30
      NXX=XX                                                             CIR   31
      GO TO 13                                                           CIR   32
 12   NXX=ARDSEC                                                         CIR   33
 13   LOWHI(LP,1)=61 - NXX                                               CIR   34
      LOWHI(LP,2)=61 + NXX                                               CIR   35
      LLP=NY + 1 - LP                                                    CIR   36
      LOWHI(LLP,1)=LOWHI(LP,1)                                           CIR   37
      LOWHI(LLP,2)=LOWHI(LP,2)                                           CIR   38
 11   CONTINUE                                                           CIR   39
      RETURN                                                             CIR   40
      END                                                                CIR   41
      SUBROUTINE CUBIC(X,Y,S,THETA)                                      CUB    1
C
C
C     THIS SUBROUTINE COMPUTES THE COLATITUDE OF A POINT FROM ITS        CUB    2
C X-Y COORDINATES IN THE VAN DER GRINTEN PROJECTION.                     CUB    3
C
C
C         NOTATION                                                       CUB    4
C
C     X       = X-COORDINATE OF POINT                                    CUB    5
C     Y       = Y-COORDINATE OF POINT                                    CUB    6
C     S       = SCALE LENGTH OF MAP, EQUAL TO 180 DEGREES OF             CUB    7
C               LONGITUDE MEASURED ALONG THE EQUATOR                     CUB    8
C     THETA   = COLATITUDE IN RADIANS                                    CUB    9
C
C
C     SUBROUTINES CALLED:                                                CUB   10
C
C         ACNE                                                           CUB   11
C
C
C     NOTES                                                              CUB   12
C
C      1. FOR FURTHER DETAILS SEE D.P. RUBINCAM, "INVERTING X,Y GRID     CUB   13
C         COORDINATES TO OBTAIN LATITUDE AND LONGITUDE IN THE VAN DER    CUB   14
C         GRINTEN PROJECTION", NASA TP 81998, AUGUST 1980.               CUB   15
C      2. S=2*RHO IN THE NOTATION OF THE PAPER CITED.                    CUB   16
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                           CUB   17
      PI=3.14159265358979D0                                              CUB   18
      PIDIV2=PI/2.0D0                                                    CUB   19
      FOURPI=4.0D0*PI                                                    CUB   20
      FAC=-1.0D0                                                         CUB   21
      Z=Y                                                                CUB   22
      IF (Z) 1,2,3                                                       CUB   23
 2    THETA=PIDIV2                                                       CUB   24
      GO TO 10                                                           CUB   25
 1    Z=DABS(Z)                                                          CUB   26
      FAC=1.0D0                                                          CUB   27
 3    CONTINUE                                                           CUB   28
      Z2=Z**2                                                            CUB   29
      T=X**2 + Z2                                                        CUB   30
      S2=S*S                                                             CUB   31
      S3=S2*S                                                            CUB   32
      S4=S3*S                                                            CUB   33
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```
      C3=S4 + 2.0DC*S3*Z + 2.CDO*S2*Z2 + 2.0DO*S*Z*T + T**2                CUB   34
      C2=-S3*Z - 3.0DC*S2*Z2 + S2*T - S*Z*T                               CUB   35
      C1= -S3*Z - S*Z*T                                                   CUB   36
      C0=S2*Z2                                                            CUB   37
      P=C2/C3                                                             CUB   38
      Q=C1/C3                                                             CUB   39
      R=CC/C3                                                             CUB   40
      A=Q - (P**2)/3.CDC                                                  CUB   41
      D=(2.CDO*(P**3) - 9.0CO*P*Q + 27.0DO*R)/27.0DO                      CUB   42
      AP=-A/3.0DO                                                         CUB   43
      U=2.CDO*DSQRT(AP)                                                   CUB   44
      W=(3.CDC*D)/(A*U)                                                   CUB   45
      WP=DSQRT(1.0CO - W**2)/W                                            CUB   46
      ANG3=DATAN(WP) + PI                                                 CUB   47
      ANG=(ANG3 + FCURPI)/3.0EO                                           CUB   48
      BEE=U*DCOS(ANG) - P/3.0EO                                           CUB   49
      THETA=PIDIV2 + FAC*BEE*PI                                           CUB   50
 1C   CCNTINUE                                                           CUB   51
      RETURN                                                              CUB   52
      END                                                                 CUB   53
      SUBROUTINE QLADRC(X,Y,S,XLMDA)                                      QUA    1
C
C
C     THIS SUBROUTINE CCMPUTES THE LONGITUDE OF A POINT FROM ITS        QUA    2
C X-Y CCORDINATES IN THE VAN DER GRINTEN PROJECTION.                    QUA    3
C
C
C          NOTATION                                                       QUA    4
C
C     X       = X-CCORDINATE OF POINT                                   QUA    5
C     Y       = Y-CCCRDINATE OF POINT                                   QUA    6
C     S       = SCALE LENGTH OF MAP, EQUAL TO 180 DEGREES OF            QUA    7
C               LONGITUDE MEASURED ALONG THE EQUATOR                    QUA    8
C     XLMDA   = LONGITUDE IN RADIANS                                    QUA    9
C
C
C     SUBROUTINES CALLED:                                               QUA   10
C
C          NONE                                                         QUA   11
C
C
C     NOTES                                                             QUA   12
C
C      1. FOR FURTHER DETAILS SEE D.P. RURINCAN, "INVERTING X,Y GRID    QUA   13
C         COORDINATES TO OBTAIN LATITUDE AND LONGITUDE IN THE VAN DER   QUA   14
C         GRINTEN PROJECTION", NASA TM 81998, AUGUST 1980.              QUA   15
C      2. S=2*RHO IN THE NOTATION OF THE PAPER CITED.                   QUA   16
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                          QUA   17
      PI=3.14159265358979CO                                             QUA   18
      IF (X) 2,1,2                                                      QUA   19
 1    XLMDA=0.000                                                       QUA   20
      GC TC 1C                                                          QUA   21
 2    CONTINUE                                                          QUA   22
      X2=X**2                                                           QUA   23
      Y2=Y**2                                                           QUA   24
      S2=S*S                                                            QUA   25
      S4=S2*S2                                                          QUA   26
      R2=S4 + 2.000*S2*(X2 - Y2) + (X2 + Y2)**2                         QUA   27
      ELL=(X2 + Y2 - S2 + DSQRT(R2))/(2.0DO*S*X)                        QUA   28
      XLMDA=ELL*PI                                                      QUA   29
 1C   CONTINUE                                                          QUA   30
      RETURN                                                            QUA   31
      END                                                               QUA   32
      SUBROUTINE VDG (PHI,XLMDA,RADMAP,NDEG,X,Y)                        VDG    1
C
C
C     THIS SUBROUTINE COMPUTES THE X,Y GRID COORDINATES OF A POINT      VDG    2
C IN THE VAN DER GRINTEN PROJECTION FROM ITS LATITUDE AND LONGITUDE.    VDG    3
C
C
C          NOTATION                                                     VDG    4
C
C     PHI     = LATITUDE OF POINT (IN DEGREES OR RADIANS)               VDG    5
C     XLMDA   = LONGITUDE OF POINT (IN DEGREES OR RADIANS)              VDG    6
C     RADMAP  = RADIUS OF MAP                                           VDG    7
C     NDEG    = 1 IF PHI AND XLMDA ARE IN DEGREES; 0 IF IN RADIANS      VDG    8
C     X       = X GRID COORDINATE                                       VDG    9
C     Y       = Y GRID COORDINATE                                       VDG   10
C
C
C     SUBROUTINES CALLED:                                               VDG   11
C
C          NONE                                                         VDG   12
C
C
C     NOTES                                                             VDG   13
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C
C      1. THE GREENWICH MERIDIAN (XLMDA=0) RUNS DOWN THE CENTER OF      VDG   14
C         THE MAP.                                                      VDG   15
C      2. THE ORIGIN X=0, Y=0 OF THE GRID COORDINATE SYSTEM IS LOCATED   VDG   16
C         AT THE CENTER OF THE MAP (PHI=0, XLMDA=0).                    VDG   17
C      3. IF THE ABSOLUTE VALUE OF BEE OR ELL .LE. EPSLON, THEN THE      VDG   18
C         VALUE IS ASSUMED TO BE ZERO. THIS IS DONE TO AVOID INFINITIES.VDG   19
C
C
      IMPLICIT REAL*8(A-H,O-Z)                                          VDG   20
      PI=3.14159265358979D0                                             VDG   21
      EPSLON=1.0D-10                                                    VDG   22
      IF (NDEG .EQ. 1) GO TO 1                                          VDG   23
      ELL=XLMDA/PI                                                      VDG   24
      BEE=PHI/PI                                                        VDG   25
      GO TO 2                                                           VDG   26
    1 ELL=XLMDA/180.0D0                                                 VDG   27
      BEE=PHI/180.0D0                                                   VDG   28
    2 CONTINUE                                                          VDG   29
      B=DABS(BEE)                                                       VDG   30
      EL=DABS(ELL)                                                      VDG   31
      IF (EL - 1.0D0) 11,11,12                                          VDG   32
   12 CONTINUE                                                          VDG   33
      IF (ELL) 13,13,14                                                 VDG   34
   13 ELL=2.0D0 + ELL                                                   VDG   35
      GO TO 15                                                          VDG   36
   14 ELL=ELL - 2.0D0                                                   VDG   37
   15 EL=DABS(ELL)                                                      VDG   38
   11 CONTINUE                                                          VDG   39
      IF (ELL) 3,4,3                                                    VDG   40
    3 SIGNL=ELL/EL                                                      VDG   41
      FXM=0.5D0*RADMAP*(EL - 1.0D0/EL)                                  VDG   42
      FXM=DABS(FXM)                                                     VDG   43
      XP=-SIGNL*FXM                                                     VDG   44
      R=0.5D0*RADMAP*(ELL + 1.0D0/ELL)                                  VDG   45
      IF (B - EPSLON) 6,6,5                                             VDG   46
    5 SIGNB=BEE/B                                                       VDG   47
      B1=DSQRT(1.0D0 - 2.0D0*E)                                         VDG   48
      B2=DSQRT(1.0D0 + 2.0D0*E)                                         VDG   49
      FYJ=RADMAP*(1.0D0 - B)**2/(B*(B2 - B1))                           VDG   50
      YJ=SIGNB*FYJ                                                      VDG   51
      S=RADMAP*(1.0D0 + B)*B1/(B*(B2 - B1))                             VDG   52
      R2=R**2                                                           VDG   53
      S2=S**2                                                           VDG   54
      XMYJ=XM**2 + YJ**2                                                VDG   55
      RS1=R2 + S2                                                       VDG   56
      RS2=R2 - S2                                                       VDG   57
      RS3=4.0D0*R2*S2                                                   VDG   58
      SQUARE=RS3 - (XMYJ - RS1)**2                                      VDG   59
      IF (SQUARE) 16,16,17                                              VDG   60
   16 RADCL=0.0D0                                                       VDG   61
      GO TO 18                                                          VDG   62
   17 RADCL=DSQRT(SQUARE)                                               VDG   63
   18 CONTINUE                                                          VDG   64
      X=(XP*(XMYJ - RS2) + SIGNL*FYJ*RADCL)/(2.0D0*XMYJ)                VDG   65
      Y=(YJ*(XMYJ + RS2) - SIGNB*FXM*RADCL)/(2.0D0*XMYJ)                VDG   66
      GO TO 10                                                          VDG   67
    4 X=0.0D0                                                           VDG   68
      IF (BEE) 7,8,7                                                    VDG   69
    8 Y=0.0D0                                                           VDG   70
      GO TO 10                                                          VDG   71
    7 Y=SIGNB*RADMAP*(1.0D0 - DSQRT(1.0D0 - 4.0D0*B**2))/(2.0D0*B)      VDG   72
      GO TO 10                                                          VDG   73
    6 Y=0.0D0                                                           VDG   74
      X=RADMAP*ELL                                                      VDG   75
   10 CONTINUE                                                          VDG   76
      RETURN                                                            VDG   77
      END                                                               VDG   78
                                                                    2531 CARDS
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