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FINAL TECHNICAL REPORT

Investigation of Lunar Crustal Structure and Isostasy

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Investigation of Lunar Crustal Structure and Isostasy

This project was originally conceived as a two-prong attack on the problem of the structure and isostatic state of the lunar crust, at a total projected cost of about $73,000. The project was started up with a funding level of $18,500, but notification of funding was quickly followed by a letter (included as Appendix A) indicating the extreme unlikelihood of further funding. Thus one project task (crustal structure) was abandoned in favor of accomplishing at least part of the other task (isostatic state).

Background

The lunar mascon basins [Muller and Sjogren, 1968] have strongly positive free air gravity anomalies, generally exceeding 100 milligals at an elevation of 100 km. The source of the anomalies is a combination of mantle uplift beneath the impact basins and susequent infilling by high-density mare basalts. The relative contribution of these two components is still somewhat uncertain, although it is generally accepted that the amount of mantle uplift greatly exceeds the thickness of the basalts [Bratt et al., 1985].

Extensive studies have been carried out of the crustal structure of mare basins, based on gravity data [Bowin et al., 1975; Sjogren and Smith, 1976; Thurber and Solomon, 1980; Phillips and Dvorak, 1981; Janle, 1981a,b; Bratt et al., 1985], and their tectonic evolution, based on compressive and extensional tectonic features [Solomon and Head, 1979; Comer et al., 1979; Solomon and Head, 1980]. The present study endeavored to develop a unified, self-consistent model of the lunar crust and lithosphere incorporating both gravity and tectonic constraints.

Method

My approach to investigating the isostatic state of the lunar crust was to evaluate the capability of separating the contributions to the lunar gravity field due to crustal thickness variations, such as those determined by Thurber and Solomon [1978] and Bratt et al. [1984), from those due to flexural support of the mascon basin loads by the lunar elastic lithosphere. To this end, a computer program was developed to forward-model the gravitational signature of elasically-supported mare basin fill. The principal variables are the elastic lithosphere thickness and the excess mass of the mare basalt fill.

The computer algorithm brings together the method for computing flexural deformation of an elastic lithosphere due to a cylindrical load [Brotchie and Silvester, 1969] with a novel expansion method for evaluating the gravity anomaly of a cylindrical anomalous mass, developed previously by the Principal Investigator (see Appendix B). Figure 1 illustrates the components of the procedure. The estimated excess mass load of the basalt fill of each mascon, approximated by a cylinder, deforms the Moon's elastic lithosphere. The lithosphere thickness for the basins have been estimated independently from flexurally-induced tectonic features: rilles and ridges [Solomon and Head, 1980]. Deformation of the lithosphere gives rise to additional contributions to the gravity field, due to depression of the relatively low density crust, and uplift of the flexural bulge. Cylindrical approximations to these anomalous masses are determined, and the total resultant gravity anomaly field (mare fill, crustal depression, bulge uplift) is evaluated using the disk expansion.

Parameters and results

Figure 2, from Solomon and Head [1980], shows the mare basins considered, along with lithosphere thickness estimates based on rilles (early stage loading) and ridges (late stage loading). The near-side Bouguer gravity anomaly map for the Moon, which primarily represents the signature of the mascons, is given in Figure 3. The gravity field is evaluated at a uniform elevation of 100 km above the means lunar surface.

I have applied this program to evaluate the ability to use the near-side gravity data to resolve the flexural component of the gravity field. In this way, an independent estimate of the Moon's elastic lithosphere thickness could be derived. One could then investigate whether the tectonically-derived value of lithosphere thickness was "frozen into" the flexural signature of the gravity field at the time of loading, in a manner similar to that proposed for the Earth's ocean basins [Watts, 1978]. Unfortunately, the results are negative. Figure 4 indicates the tiny difference the effect of flexural support contributes to the gravity field around Mare Crisium even when the lithosphere thickness there is varied from 80 km (the rille estimate) to 125 km (the ridge estimate). Thus the existing global gravity data cannot be used to derive independent constraints on the lunar lithosphere thickness.

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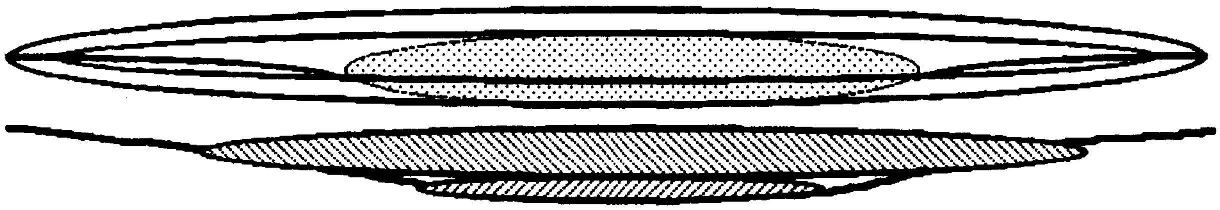

Figure 1. Schematic diagram of the approach for calculating the flexure and resultant gravity field due to a mascon load. The top cylinder represents the excess density of the mascon, while the bottom two represent density deficiencies due to flexure of the lunar crust. A positive annulus of density is used to represent the flexural bulge.

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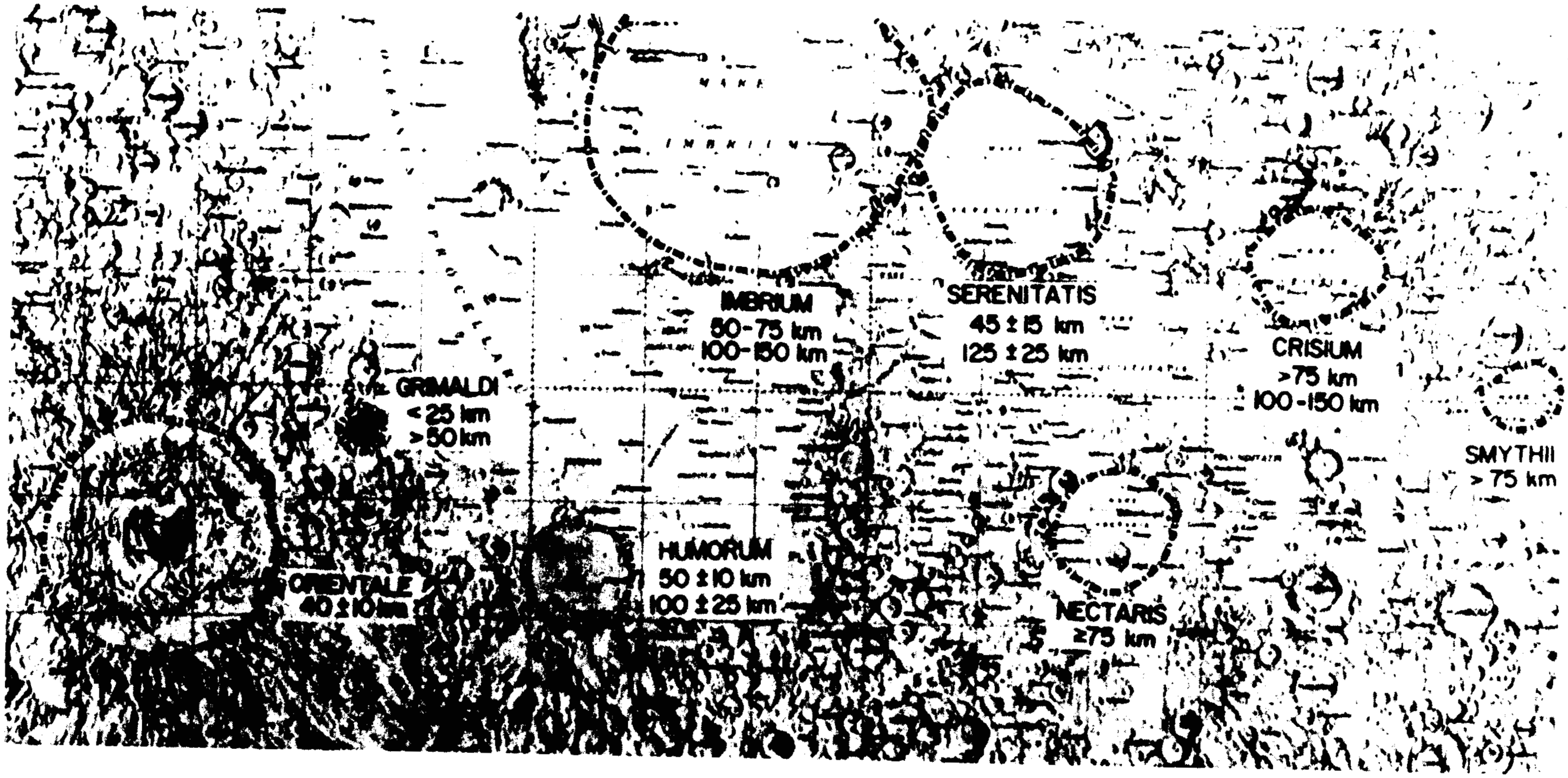


Figure 2. Mare basins included in the isostatic modeling, and elastic lithosphere thickness estimates based on rille and ridge positions. From Solomon and Head [1980].

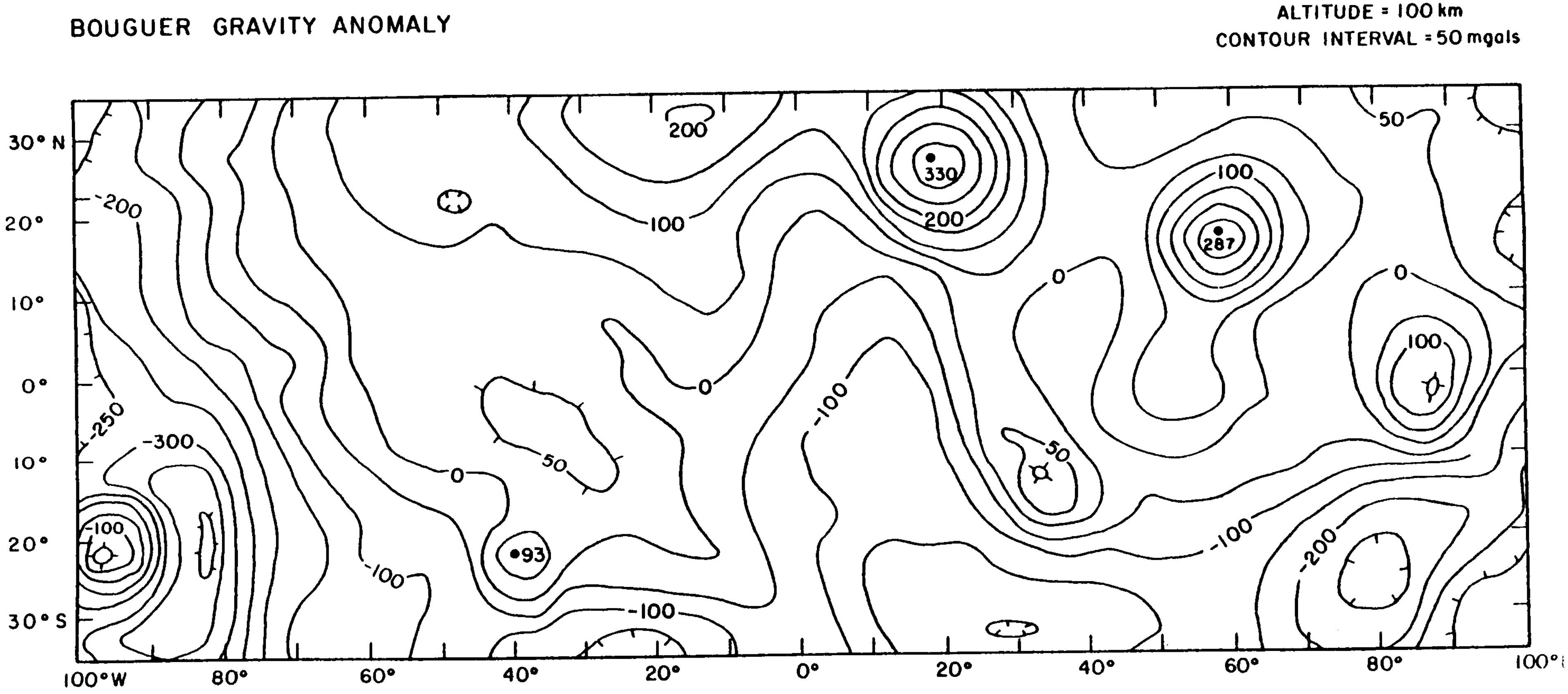
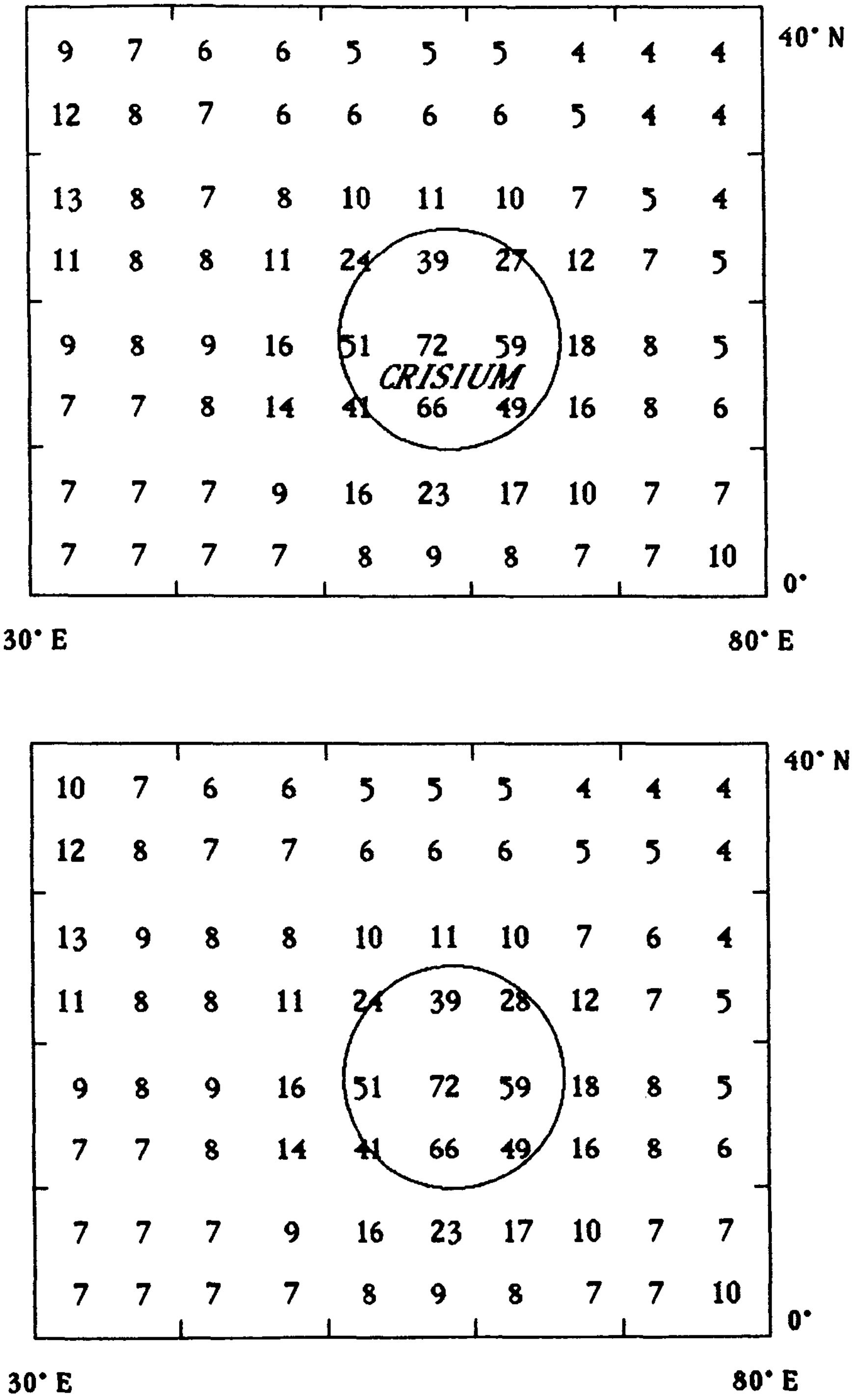


Figure 3. Bouguer gravity anomaly for the lunar near side, evaluated at an elevation of 100 km. Note the significant anomalies associated with the major mare basins (the mascons).



9	7	6	6	5	5	5	4	4	4
12	8	7	6	6	6	6	5	4	4
13	8	7	8	10	11	10	7	5	4
11	8	8	11	24	39	27	12	7	5
9	8	9	16	51	72	59	18	8	5
7	7	8	14	41	66	49	16	8	6
7	7	7	9	16	23	17	10	7	7
7	7	7	7	8	9	8	7	7	10

10	7	6	6	5	5	5	4	4	4
12	8	7	7	6	6	6	5	5	4
13	9	8	8	10	11	10	7	6	4
11	8	8	11	24	39	28	12	7	5
9	8	9	16	51	72	59	18	8	5
7	7	8	14	41	66	49	16	8	6
7	7	7	9	16	23	17	10	7	7
7	7	7	7	8	9	8	7	7	10

Figure 4. Comparison of computed gravity anomalies around Mare Crisium for thin (top) versus thick (bottom) lithosphere thickness estimates. Differences are in the milligal and below range.

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Appendix A

Reply to Attn of EL

Dear Colleague:

The FY 86 budget as submitted by the President to Congress will affect the planetary geology and geophysics program as part of the larger solar system exploration program. The present outlook for geology and geophysics indicates a reduction of about 300K. Although core SR&T funds for our program were increased 600K above the FY 85 level, the overall reduction reflects a cut of about 900K from data analysis (outer planets and Venus) projects. Many of the projects now classified as data analysis either belong in the core program or will provide important contributions to the interpretation of new data from Galileo and VRM, the next two NASA planetary missions, as well as the Voyager Uranus encounter. For this reason, most of the data analysis programs will necessarily compete with elements in the SR&T core program, and some are already being reassigned to the core program.

The impact of the funding reduction will be felt in several ways: 1) most principal investigators will have to lower sights and trim their funding requests, 2) some P.I.'s may suffer substantial cuts in their proposed budgets. This will be particularly true for projects where overlap or duplication of effort occurs and where little progress is shown in the work, 3) aspiring new P.I.'s, research assistants, graduate students, and other skilled personnel will probably be most affected. This at a time when unfortunately (and inopportunely) our annual brochure proclaiming opportunities in geology and geophysics will soon be distributed to universities and colleges.

There may be other adverse effects not yet realized, and I solicit your help in bringing these to light -- but thoughtfully and without over dramatizing their consequence. More importantly, it is very necessary to increase our visibility on the positive side. To this end, it would be very helpful to receive a brief description or outline of significant discoveries or new concepts developed from your work. Ordinarily these accomplishments are shown on your T43's, but sometimes their importance is obscure or not fully recognized in this report form. If you believe that results from your work need further amplification please follow through on this and send them to me; your comments will be appreciated.

Sincerely,

David H. Scott

David H. Scott
Discipline Scientist
Planetary Geology and Geophysics Program
Solar System Exploration Division
Office of Space Science and Applications

Appendix B

Binomial expansion method for calculating the gravity anomaly due to a thin disk.

The integral representation for the potential at point $\underline{r}$ of an infinitely thin disk of radius a, surface density d, centered at the coordinate origin, is given by:

$$U(\underline{r}) = Gd \int_0^a \int_0^{2\pi} \| \underline{r} - \underline{r}' \|^{-1} \, r' \, d\theta \, dr' \qquad \text{(B1)}$$

where G is the gravitational constant (see Figure B1). The distance between points $\underline{r}$ and $\underline{r}'$ can be expressed as

$$\| \underline{r} - \underline{r}' \| = (r^2 + r'^2 - 2\, r\, r' \cos X)^{1/2} \qquad \text{(B2)}$$

where X is the angle between $\underline{r}$ and $\underline{r}'$. We can factor out the quantity $(r^2 + r'^2)$ from the right hand side of B2 and define q as

$$q = r\, r' / (r^2 + r'^2) \qquad \text{(B3)}$$

and then rewrite B1 as

$$U(\underline{r}) = Gd \int_0^a \int_0^{2\pi} r'/(r^2 + r'^2) \; (1 - 2q \cos X)^{-1/2} \, r' \, d\theta \, dr' \qquad \text{(B4)}$$

We can substitute the binomial expansion of the last term in B4, given in closed form by

$$(1 - 2q)^{-1/2} = \sum_{n=0}^{\infty} q^n/n! \; (2n-1)(2n-3)\cdots(1) \qquad \text{(B5)}$$

If we now replace cos X with ($\sin \beta \cos \theta$) and integrate over $d\theta$, the odd powers of n drop out, so replacing n with 2k, we are left with

$$U(\underline{r}) = 2^{\pi} Gd \sum_{k=0}^{\infty} (4k)!/[2^{4k} (k!)^2 (2k)!] \; (\sin \beta)^{2k} \int_0^a q^{2k} \, r' \, dr' \qquad \text{(B6)}$$

The remaining integration can be solved easily by parts for any power k.

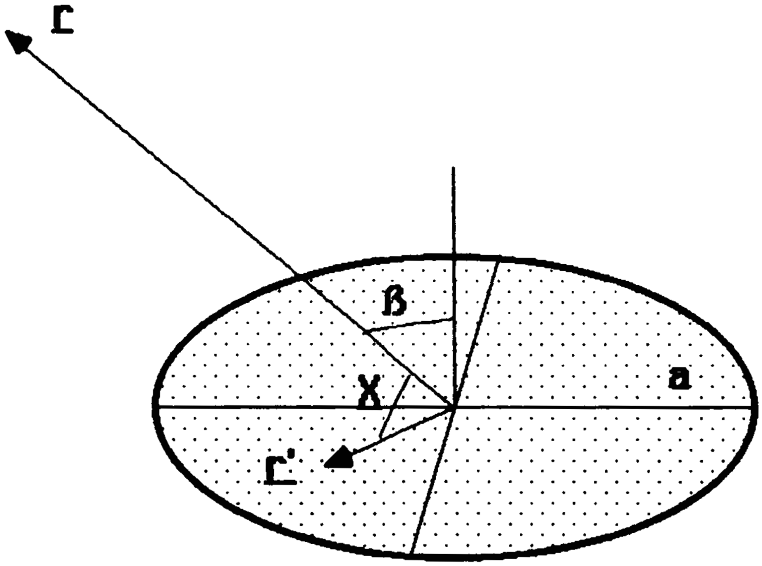


Figure B1. Geometry and notation for the disk mass potential expansion.