Gravity Surveying

Introduction

Gravity surveying…

Investigation on the basis of relative variations in the Earth´gravitational field arising from difference of density between subsurface rocks

Application

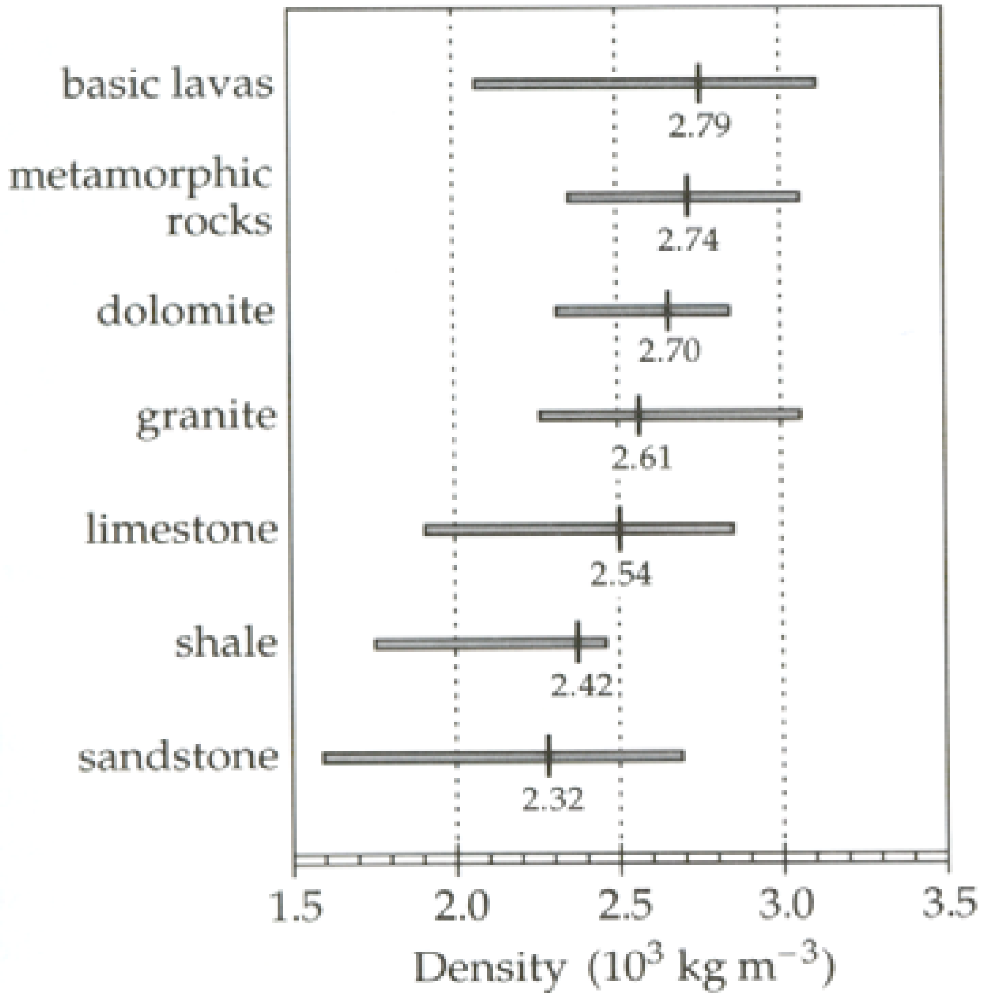
- Exploration of fossil fuels (oil, gas, coal)
- Exploration of bulk mineral deposit (mineral, sand, gravel)
- Exploration of underground water supplies
- Engineering/construction site investigation
- Cavity detection
- Glaciology
- Regional and global tectonics
- Geology, volcanology
- Shape of the Earth, isostasy
- Army

Structure of the lecture

1. Density of rocks
2. Equations in gravity surveying
3. Gravity of the Earth
4. Measurement of gravity and interpretation
5. Microgravity: a case history
6. Conclusions

1. Density of rocks

Rock density



Rock density depends mainly on…

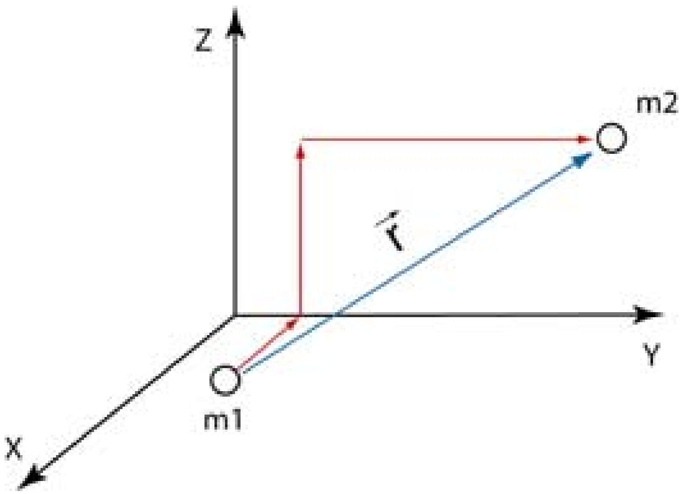
- Mineral composition
- Porosity (compaction, cementation)

Lab or field determination of density is useful for anomaly interpretation and data reduction

2. Equations in gravity surveying

First Newton´s Law

Newton´s Law of Gravitation



$$\vec{F} = -\frac{G\, m_1\, m_2}{r^2}\,\vec{r}$$

$$|r| = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

Gravitational constant $G = 6.67 \times 10^{-11} \quad \mathrm{m^3 kg^{-1} s^{-2}}$

Second Newton´s Law

$$\vec{F} = m\,\vec{a}$$

$$\vec{a} = -\frac{G\,M}{R^2}\,\vec{r} = \vec{g}_N$$

$$g_N \cong 9.81 \quad \mathrm{m/s^2}$$

g_N: gravitational acceleration or „gravity“

for a spherical, non-rotating, homogeneous Earth, g_N is everywhere the same

$M = 5.977 \times 10^{24} \quad \mathrm{kg}$ mass of a homogeneous Earth

$R = 6371 \quad \mathrm{km}$ mean radius of Earth

Units of gravity

- 1 gal = 10^{-2} m/s^2
- 1 mgal = 10^{-3} gal = 10^{-5} m/s^2
- 1 μgal = 10^{-6} gal = 10^{-8} m/s^2 (precision of a gravimeter for geotechnical surveys)

- Gravity Unit: 10 gu = 1 mgal

- Mean gravity around the Earth: 9.81 m/s^2 or 981000 mgal

Keep in mind…

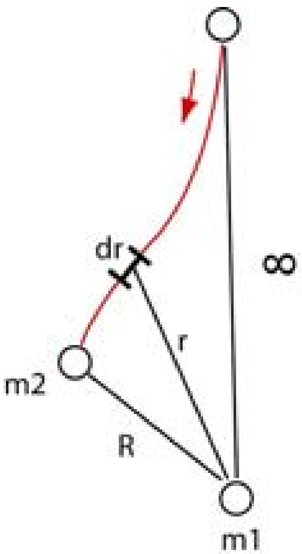
…that in environmental geophysics,
we are working with values about…

0.01-0.001 mgal ≈ 10^{-8} - 10^{-9} g_N !!!

Gravitational potential field

The gravitational potential field is conservative (i.e. the work to move a mass in this field is independent of the way)

The first derivative of *U* in a direction gives the component of gravity in that direction

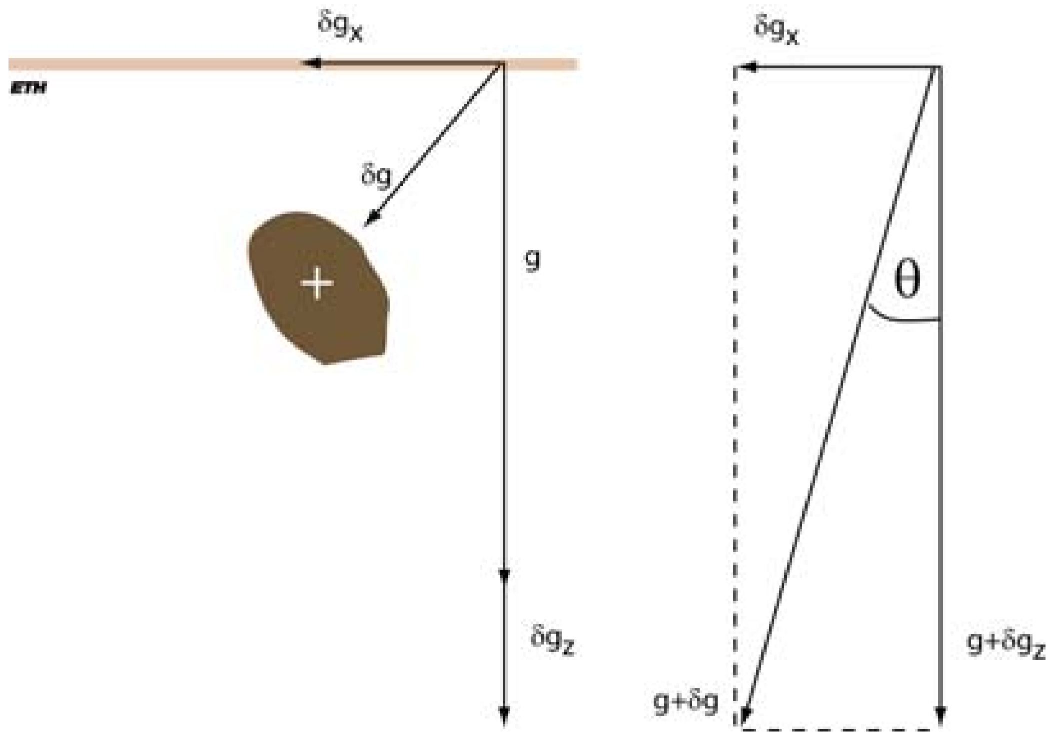


$$\nabla U = \vec{g} = \frac{\vec{F}}{m_2} \quad \text{with} \quad \nabla U = \frac{\partial U}{\partial x}\vec{i} + \frac{\partial U}{\partial y}\vec{j} + \frac{\partial U}{\partial z}\vec{k}$$

$$U = \int_{\infty}^{R} \vec{g}\cdot\vec{r}\; dr = -G\, m_1 \int_{\infty}^{R} \frac{dr}{r^2} = \frac{G\, m_1}{R}$$

Measurement component

The measured perturbations in gravity effectively correspond to the vertical component of the attraction of the causative body

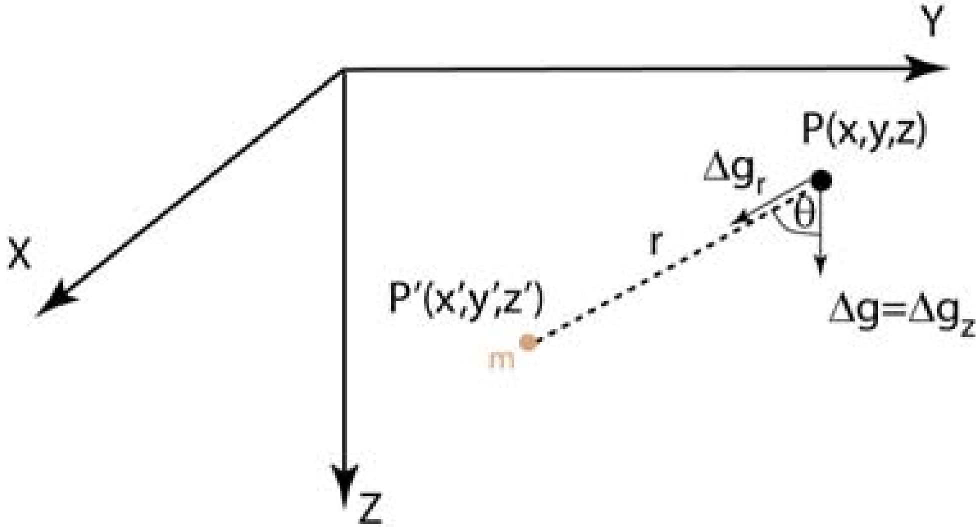


we can show that θ is usually insignifiant since $\delta g_z << g$

Therefore…

$$\delta g \approx \delta g_z$$

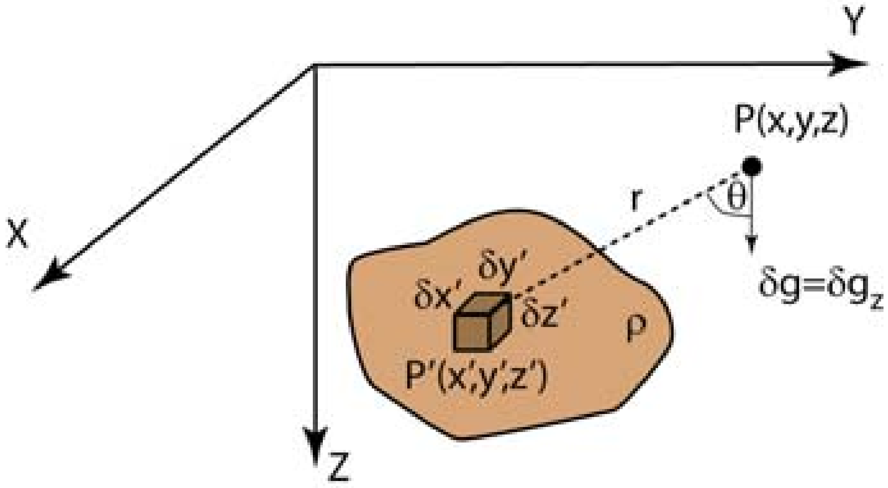
Grav. anomaly: point mass



$$\Delta g_r = \frac{Gm}{r^2} \quad \text{from Newton's Law}$$

$$\Delta g = \Delta g_z = \frac{Gm}{r^2}\cos\theta = \frac{Gm(z'-z)}{r^3}$$

Grav. anomaly: irregular shape



$$\Delta g = \frac{Gm(z'-z)}{r^3}$$

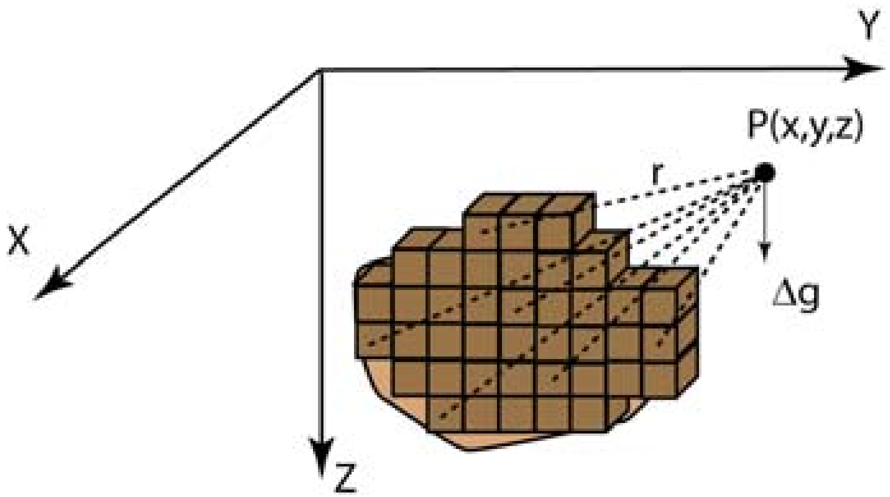
for $\delta m = \rho\, \delta x' \delta y' \delta z'$ we derive:

$$\delta g = \frac{G\rho(z'-z)}{r^3}\delta x' \delta y' \delta z'$$

with ρ the density (g/cm^3)

$$r = \sqrt{(x'-x)^2 + (y'-y)^2 + (z'-z)^2}$$

Grav. anomaly: irregular shape



for the whole body:

$$\Delta g = \sum\sum\sum \frac{G\rho(z'-z)}{r^3}\delta x'\delta y'\delta z'$$

if $\delta x', \delta y'$ and $\delta z'$ approach zero:

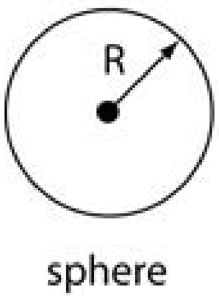
$$\Delta g = \iiint \frac{G\rho(z'-z)}{r^3}dx'dy'dz'$$

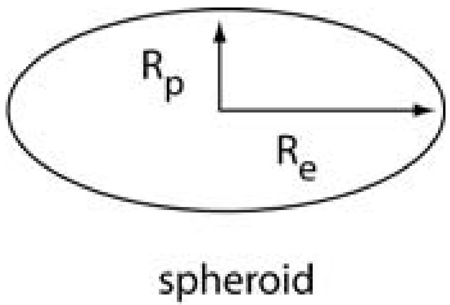
Conclusion: the gravitational anomaly can be efficiently computed! The direct problem in gravity is straightforward: Δg is found by summing the effects of all elements which make up the body

3. Gravity of the Earth

Shape of the Earth: spheroid

- Spherical Earth with R=6371 km is an approximation!
- Rotation creates an ellipsoid or a spheroid



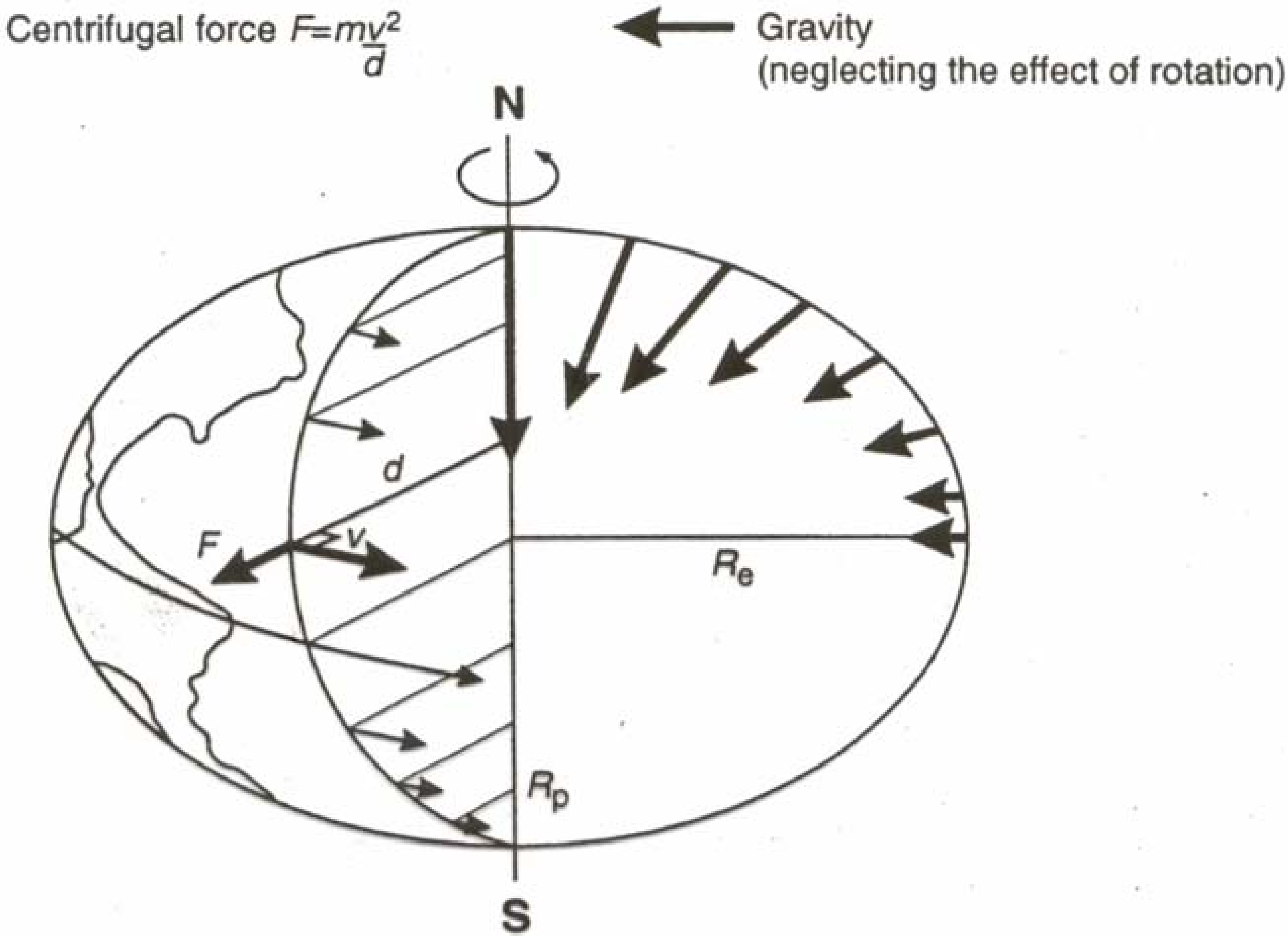


$$\frac{R_e - R_p}{R_e} = \frac{1}{298.247}$$

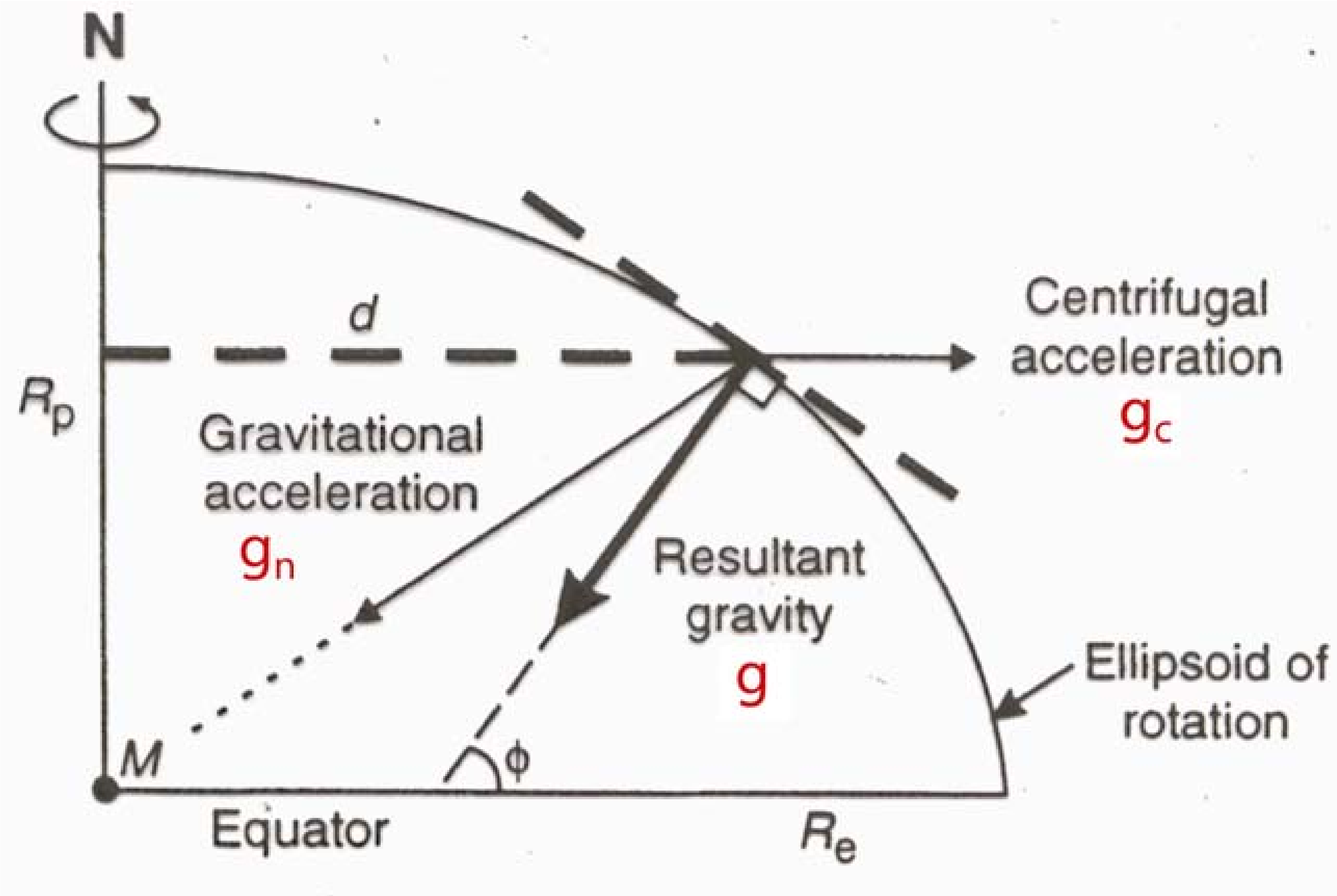
Deviation from a spherical model:

$$R_e - R = 7.2 \quad \text{km}$$

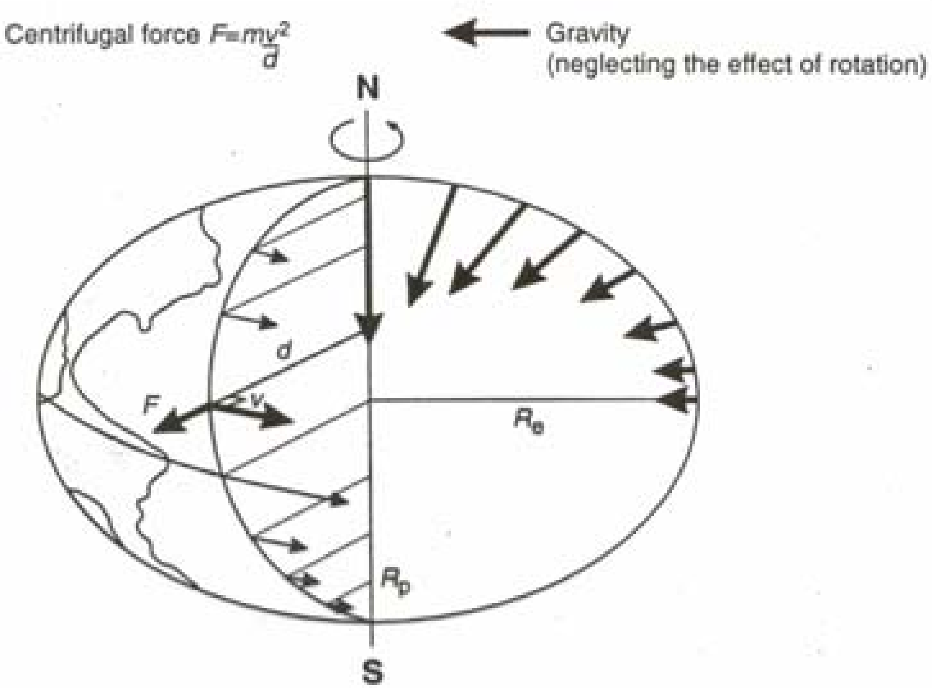
$$R - R_p = 14.3 \quad \text{km}$$

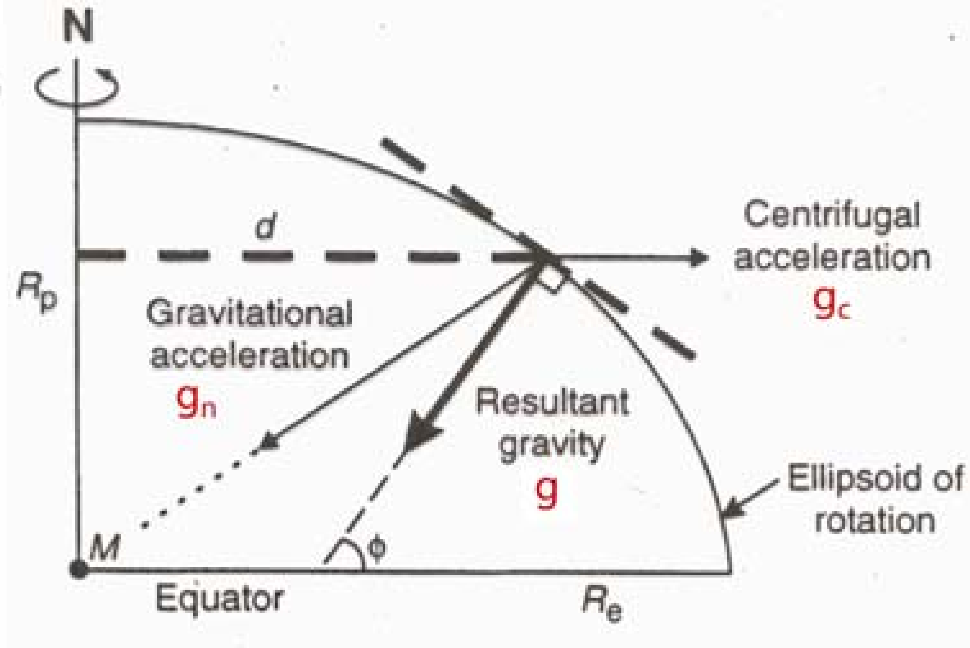


Centrifugal force $F=\frac{mv^2}{d}$
Gravity
(neglecting the effect of rotation)
N
S
d
F
v
R_e
R_p



The Earth´s ellipsoidal shape, rotation, irregular surface relief and internal mass distribution cause gravity to vary over it´s surface





$$g = g_n + g_C = G\left(M \big/ R^2 - \omega^2 R \cos\phi \right)$$

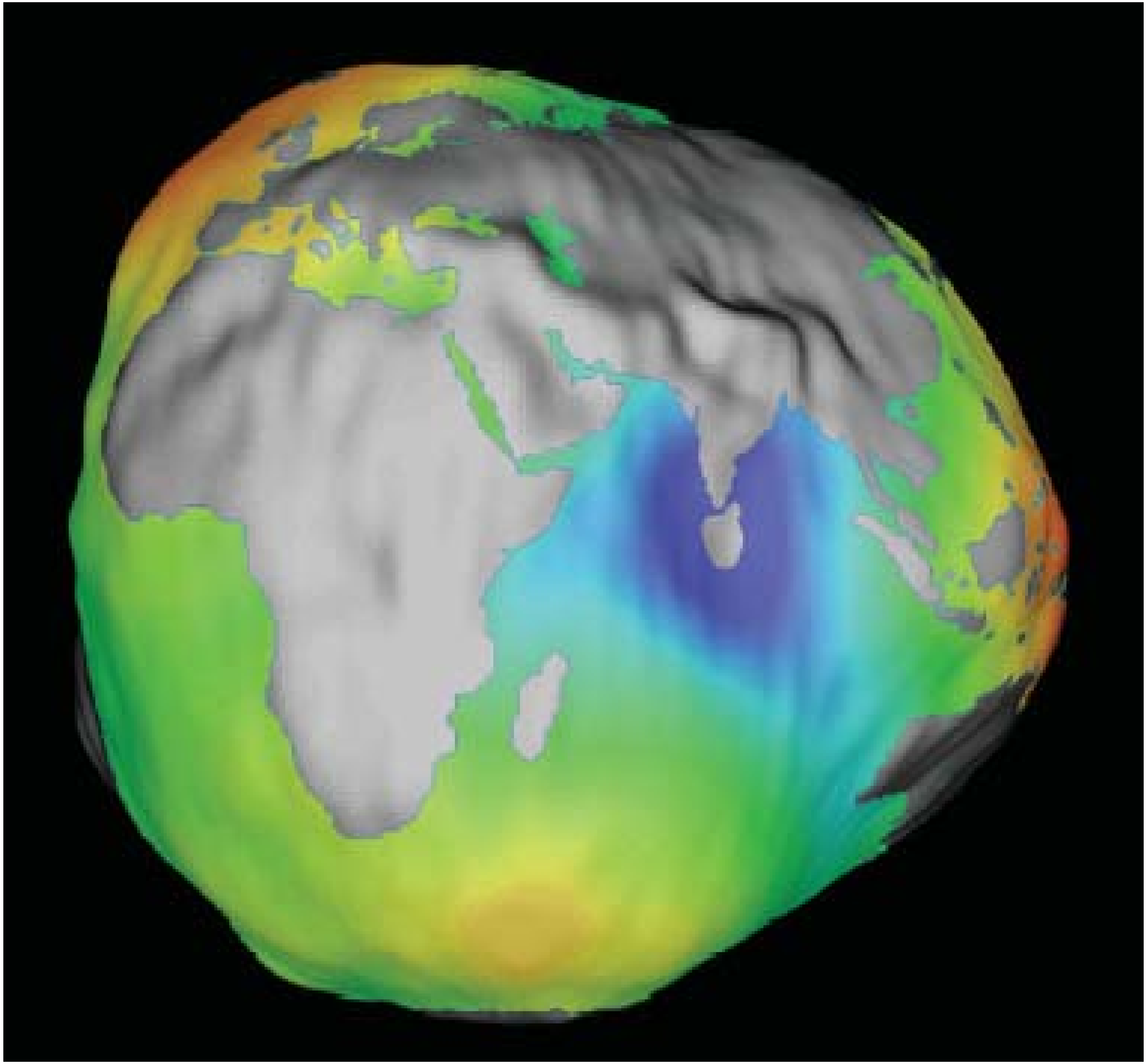
- From the equator to the pole: g_n increases, g_c decreases
- Total amplitude in the value of g: 5.2 gal

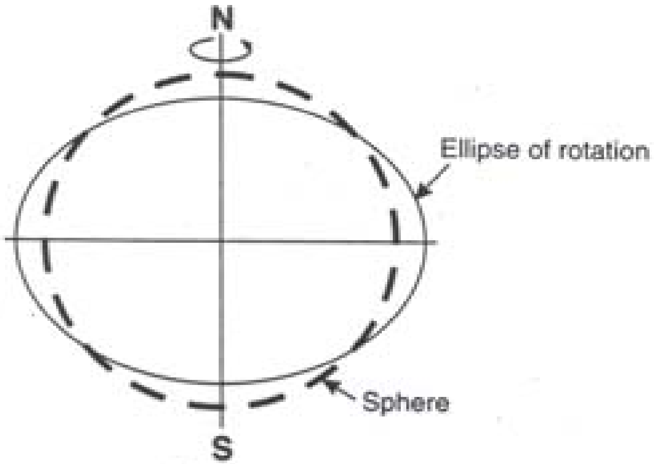
Reference spheroid

- The reference spheroid is an oblate ellipsoid that approximates the mean sea-level surface (geoid) with the land above removed
- The reference spheroid is defined in the Gravity Formula 1967 and is the model used in gravimetry
- Because of lateral density variations, the geoid and reference spheroid do not coincide

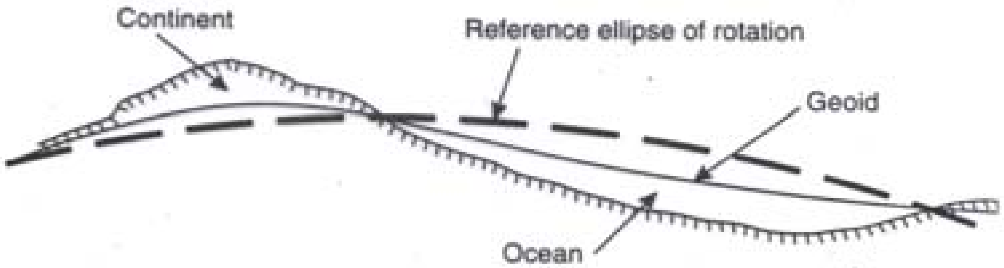
Shape of the Earth: geoid

- It is the sea level surface (equipotential surface U=constant)
- The geoid is everywhere perpendicular to the plumb line

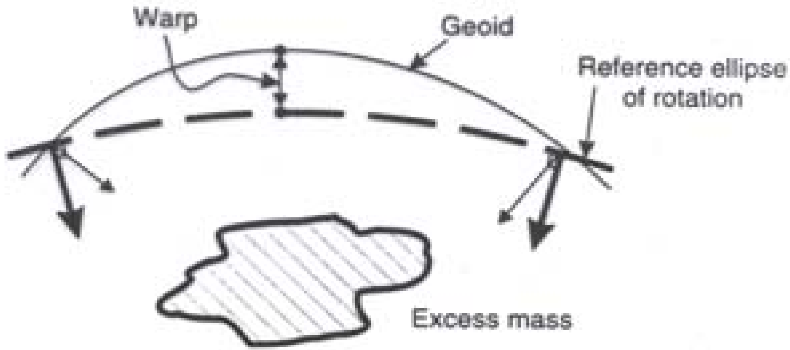



N
Ellipse of rotation
Sphere
S

(A)


Continent
Reference ellipse of rotation
Geoid
Ocean

(B)


Warp
Geoid
Reference ellipse
of rotation
Excess mass

Spheroid versus geoid

Geoid and spheroid usually do not coincide (India -105m, New Guinea +73 m)