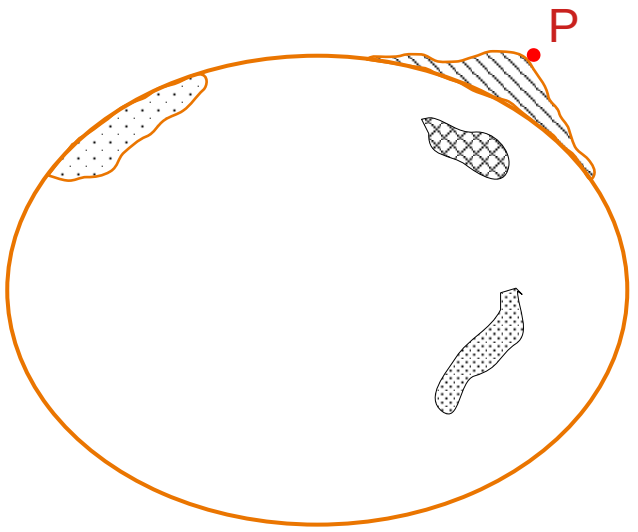
Integração de Métodos Geofísicos

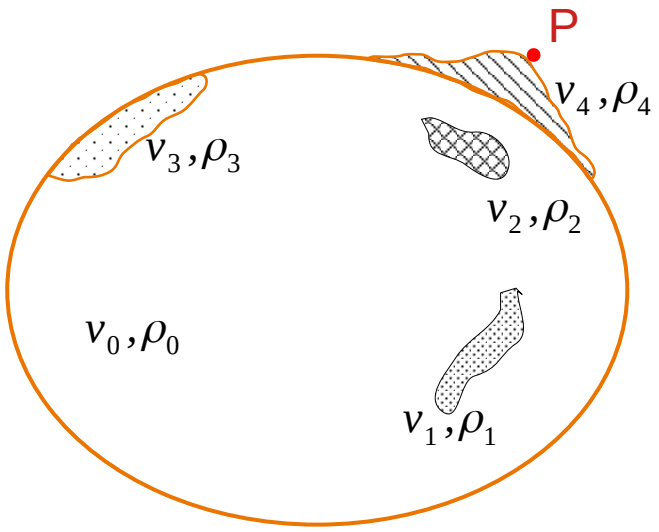
Gravimetria – Parte 2

PÓS::GRADUAÇÃO
DINÂMICA
DOS **OCEANOS**
E DA TERRA
UFF

Terra Verdadeira



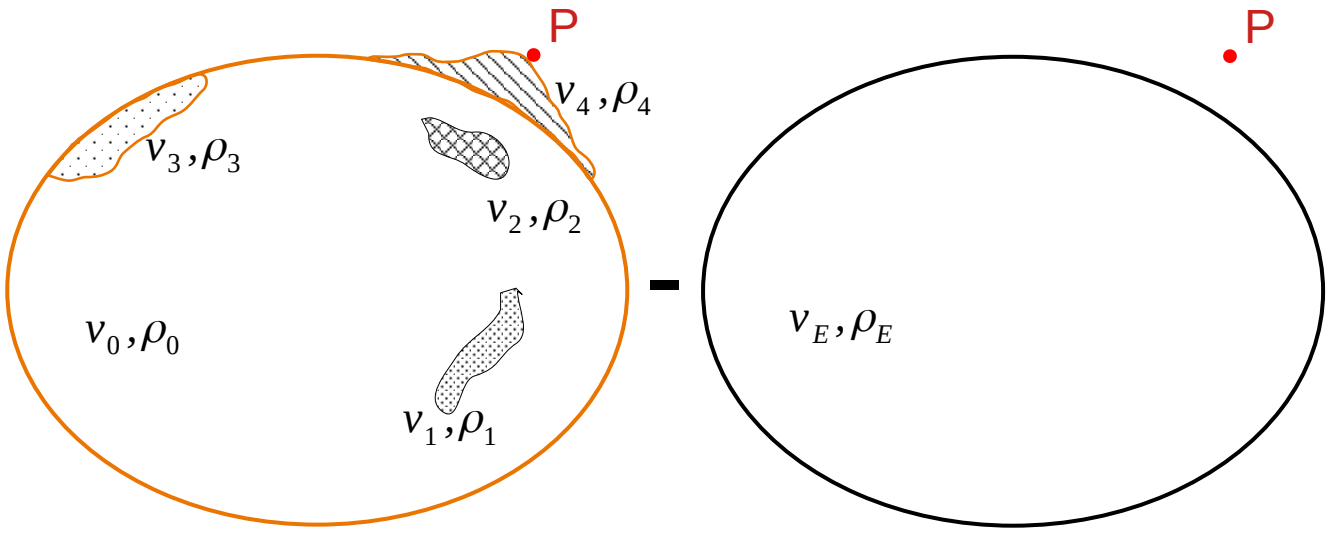
Terra Verdadeira



P = (x, y, z)

Terra Verdadeira

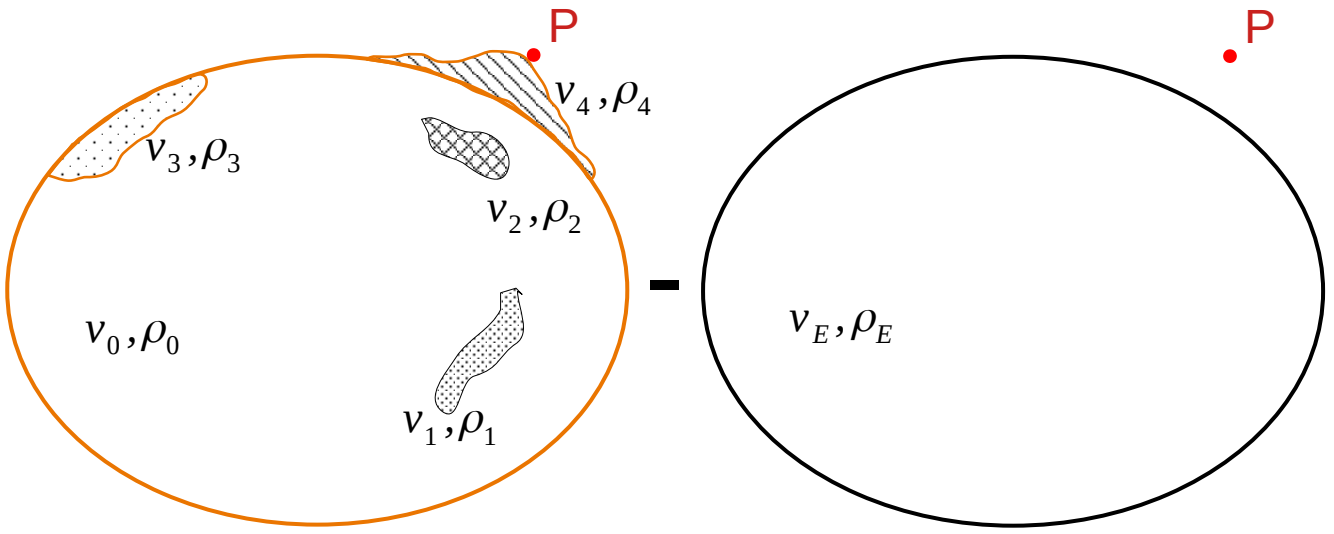
Terra Normal



P = (x, y, z)

Terra Verdadeira

Terra Normal



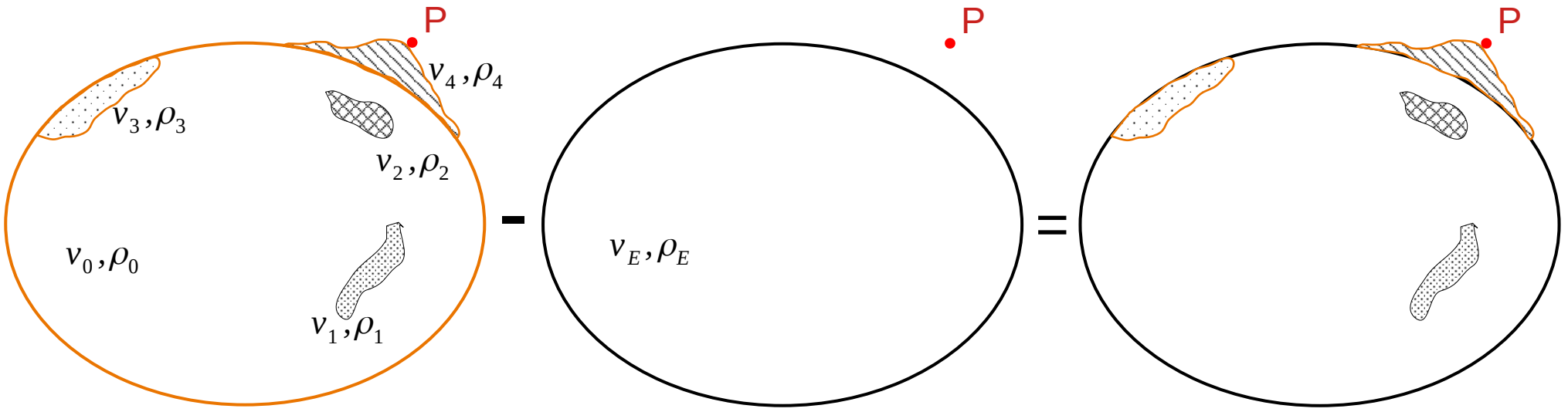
$$\nu_E = \nu_0 \cup \nu_1 \cup \nu_2 \cup \nu_3 \cup \nu_4$$

P = (x, y, z)

Terra Verdadeira

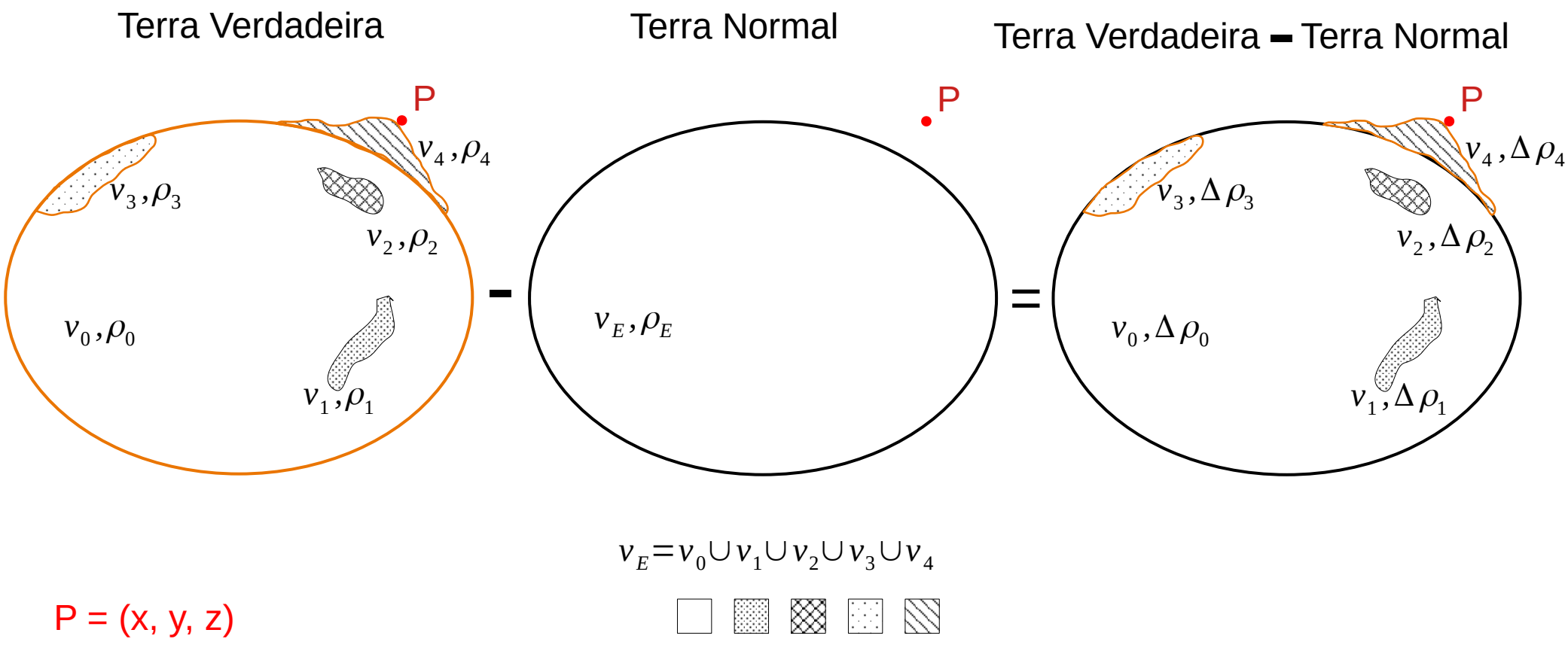
Terra Normal

Terra Verdadeira − Terra Normal



$$\nu_E = \nu_0 \cup \nu_1 \cup \nu_2 \cup \nu_3 \cup \nu_4$$

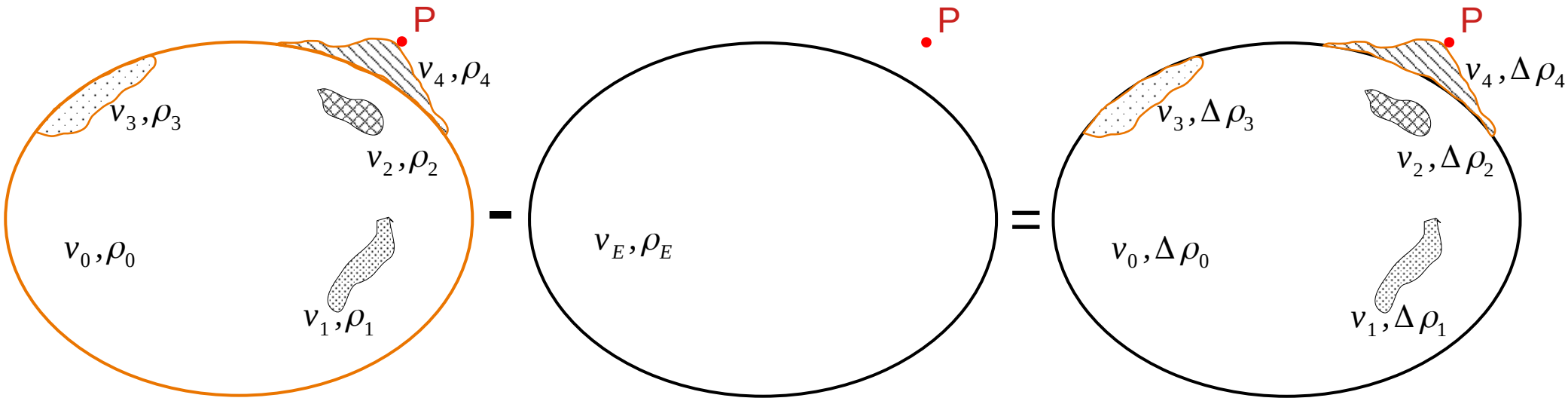
P = (x, y, z)


Terra Verdadeira
Terra Normal
Terra Verdadeira – Terra Normal
P
P
P
ν_4, ρ_4
ν_3, ρ_3
ν_2, ρ_2
ν_0, ρ_0
ν_1, ρ_1
ν_E, ρ_E
$\nu_4, \Delta\rho_4$
$\nu_3, \Delta\rho_3$
$\nu_2, \Delta\rho_2$
$\nu_0, \Delta\rho_0$
$\nu_1, \Delta\rho_1$
$\nu_E = \nu_0 \cup \nu_1 \cup \nu_2 \cup \nu_3 \cup \nu_4$
P = (x, y, z)

Terra Verdadeira

Terra Normal

Terra Verdadeira − Terra Normal



P = (x, y, z)

$\nu_E = \nu_0 \cup \nu_1 \cup \nu_2 \cup \nu_3 \cup \nu_4$

$\Delta\rho_0 = \rho_0 - \rho_E$

$\Delta\rho_1 = \rho_1 - \rho_E$

$\Delta\rho_2 = \rho_2 - \rho_E$

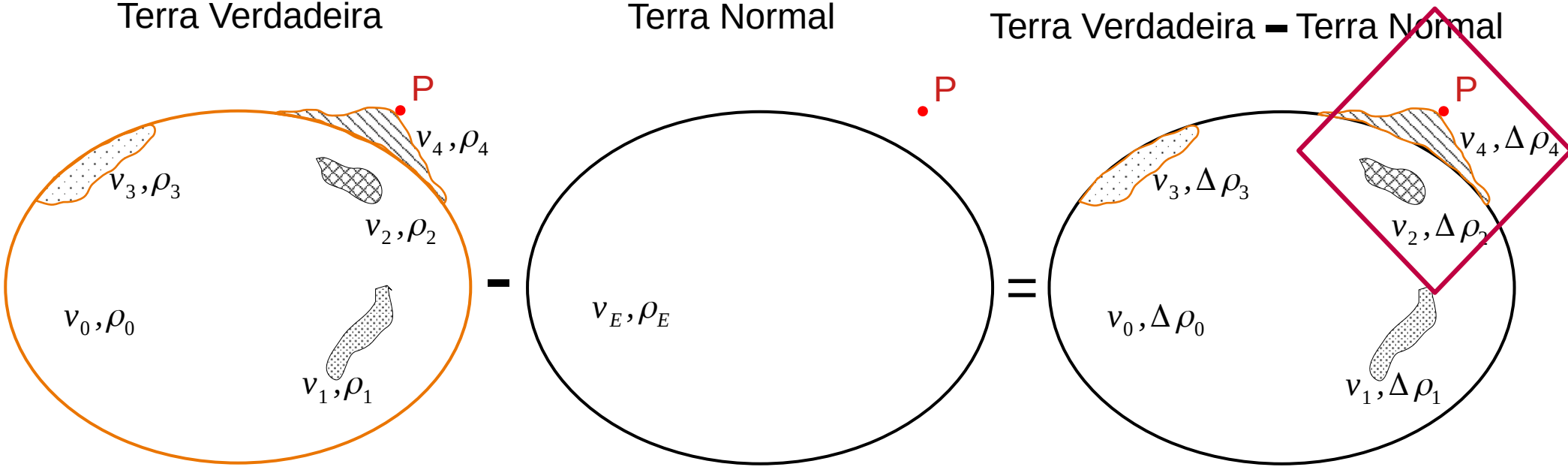
$\Delta\rho_3 = \rho_3 - \rho_E$

$\Delta\rho_4 = \rho_4 - 0 = \rho_4$

Terra Verdadeira

Terra Normal

Terra Verdadeira − Terra Normal



P = (x, y, z)

$v_E = v_0 \cup v_1 \cup v_2 \cup v_3 \cup v_4$

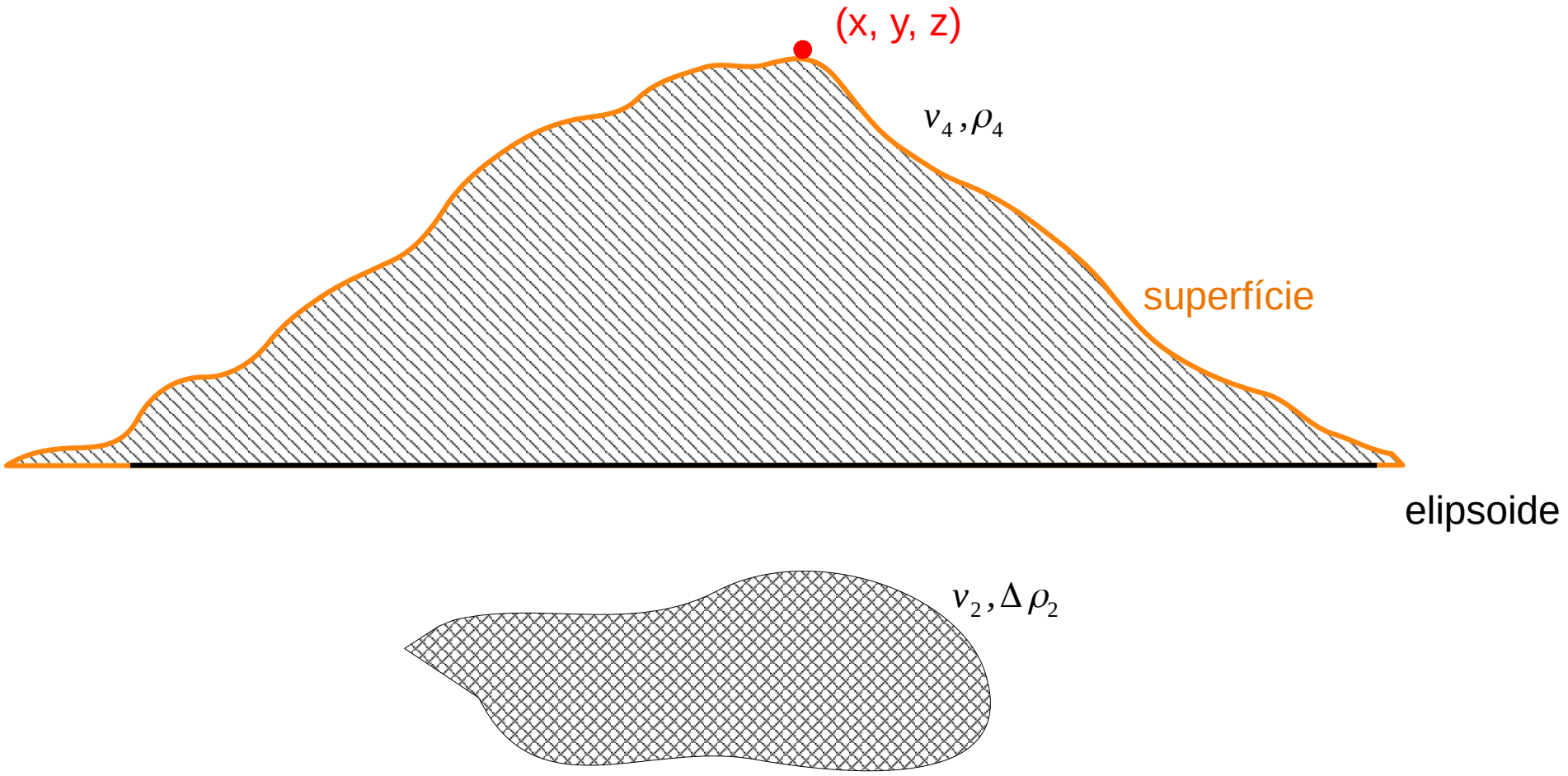
$\Delta\rho_0 = \rho_0 - \rho_E$

$\Delta\rho_1 = \rho_1 - \rho_E$

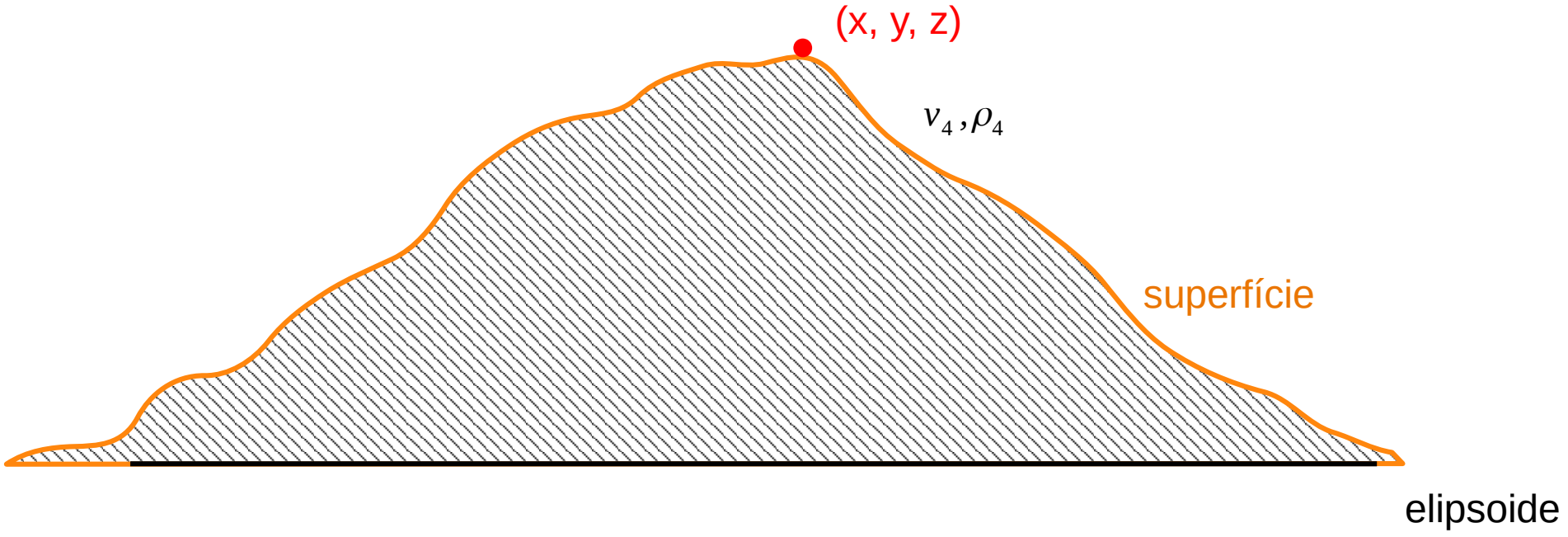
$\Delta\rho_2 = \rho_2 - \rho_E$

$\Delta\rho_3 = \rho_3 - \rho_E$

$\Delta\rho_4 = \rho_4 - 0 = \rho_4$

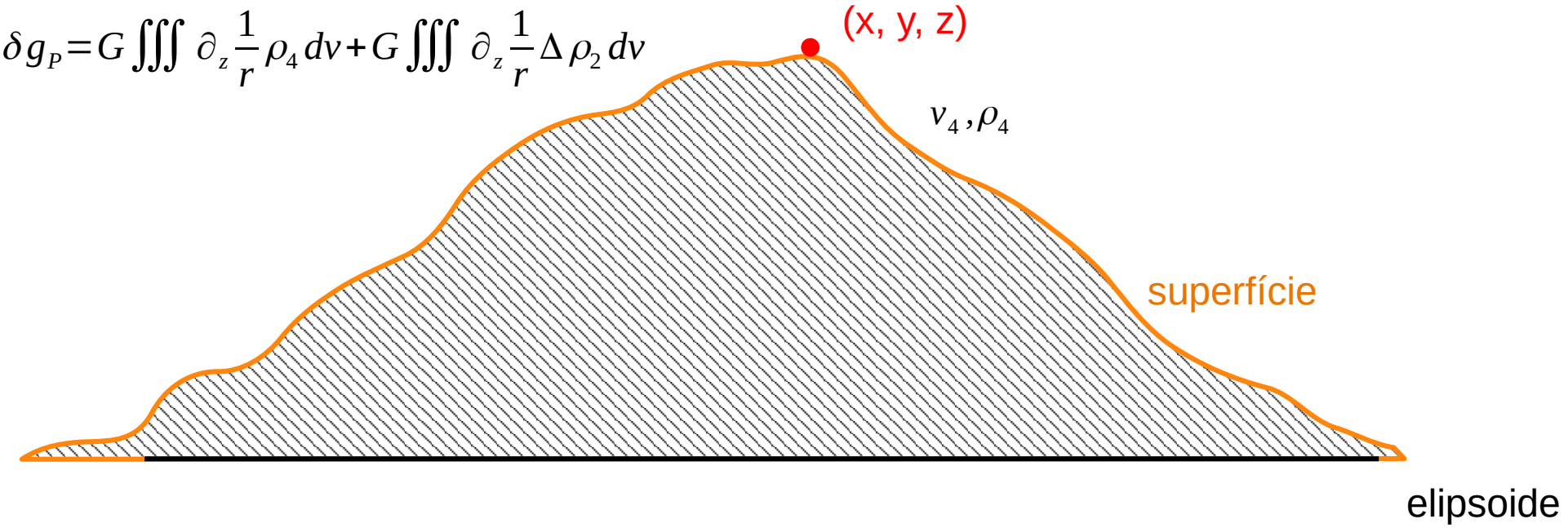

(x, y, z)
v_4, ρ_4
superfície
elipsoide
$v_2, \Delta\rho_2$

$$\delta g_P = g_P - \gamma_P$$



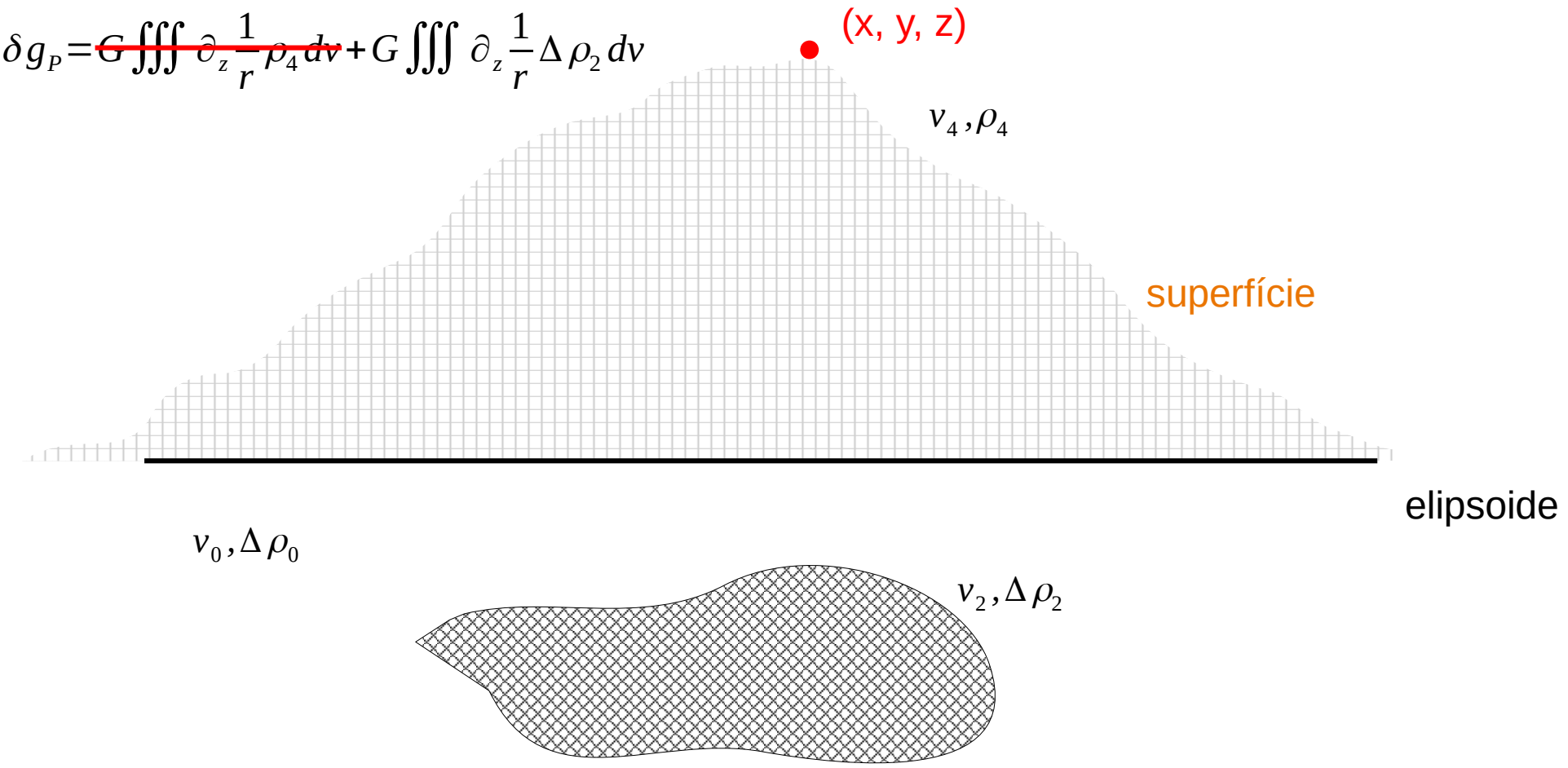
$$\delta g_P = g_P - \gamma_P$$

$$\delta g_P = G\iiint \partial_z \frac{1}{r}\rho_4\, dv + G\iiint \partial_z \frac{1}{r}\Delta\rho_2\, dv$$

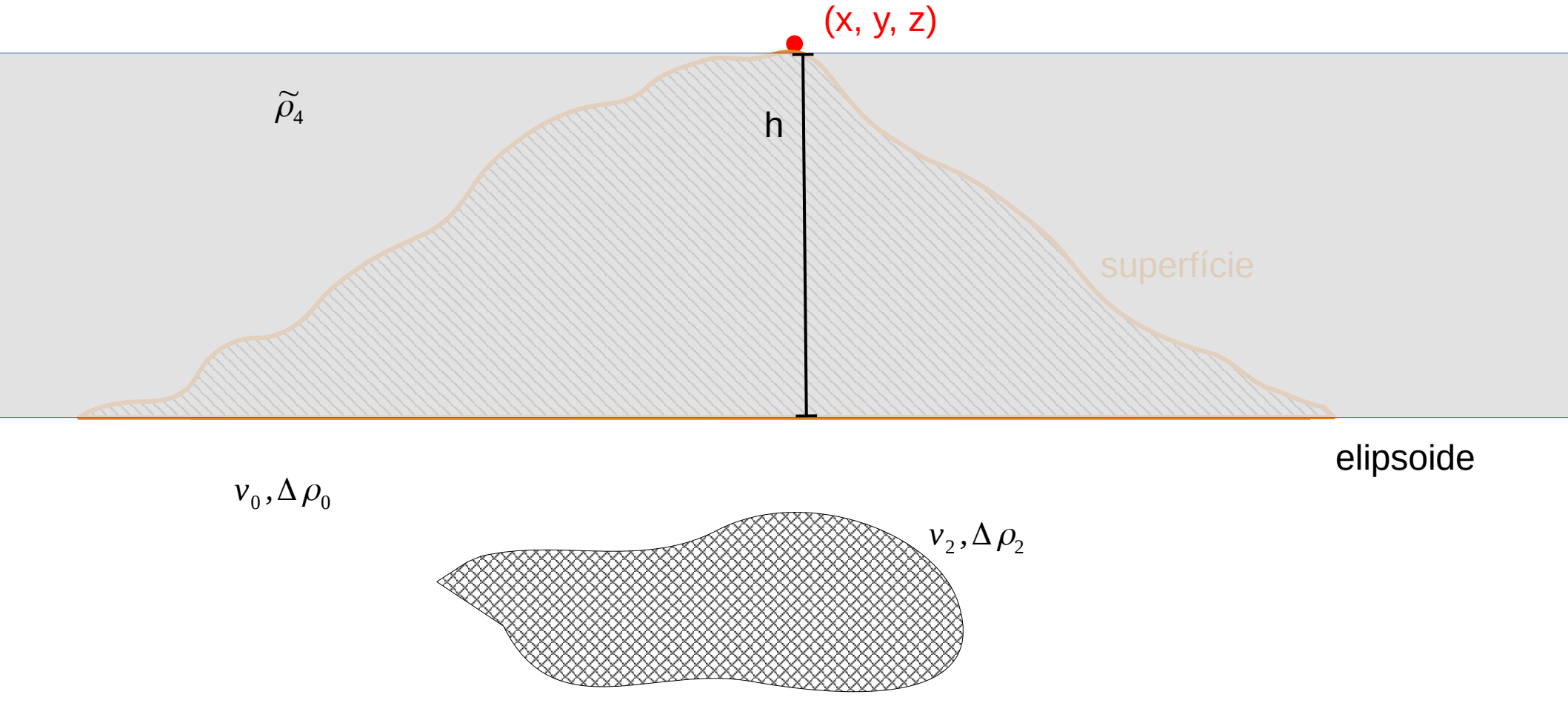


$$\delta g_P = g_P - \gamma_P$$

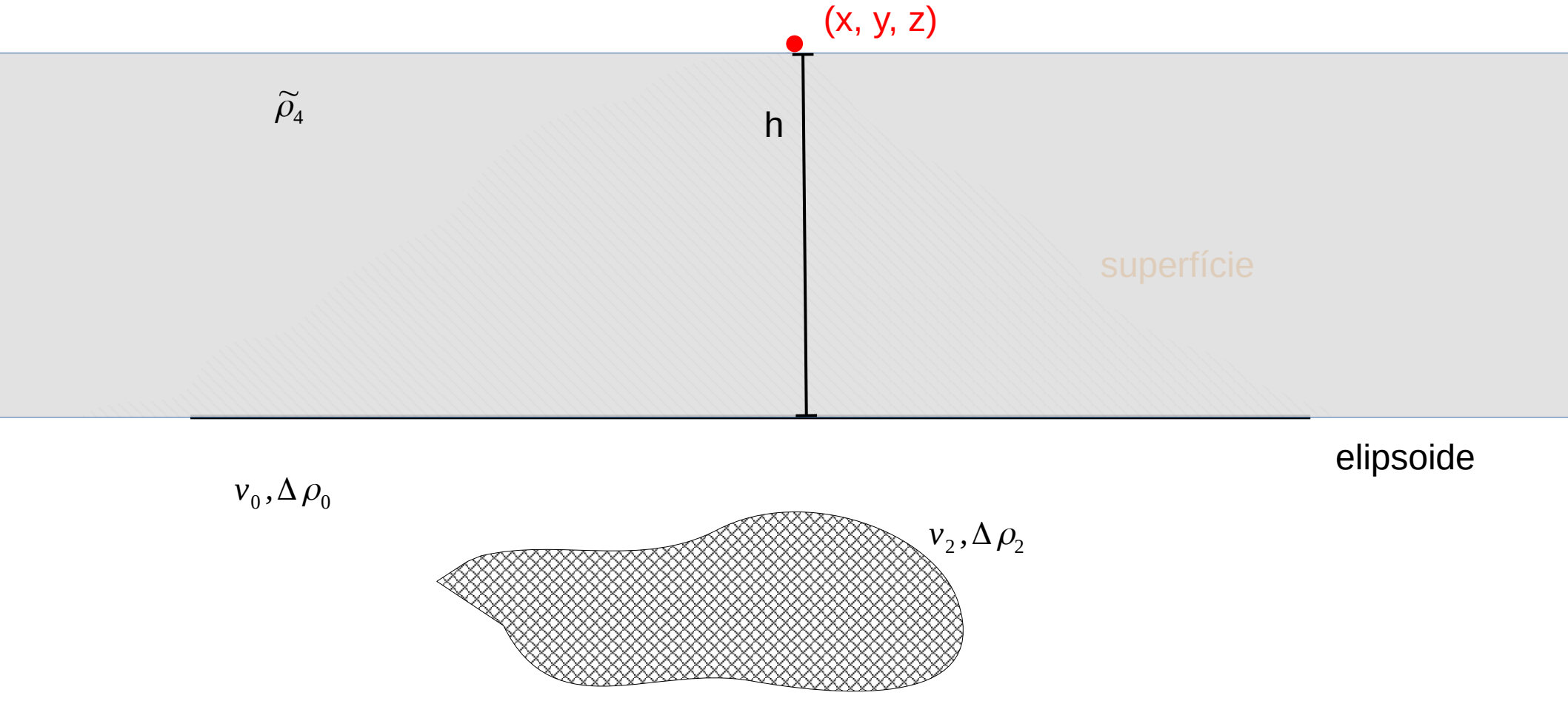
$$\delta g_P = \cancel{G \iiint \partial_z \frac{1}{r} \rho_4 \, dv} + G \iiint \partial_z \frac{1}{r} \Delta\rho_2 \, dv$$



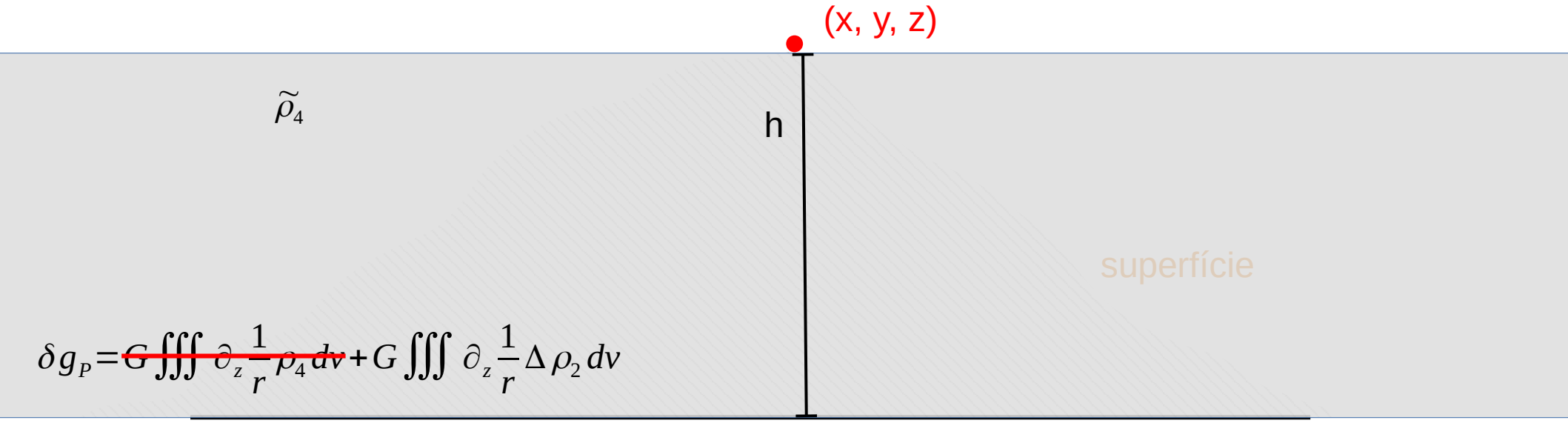
$$\delta g_P = g_P - \gamma_P$$



$$\delta g_P = g_P - \gamma_P - 2\pi G \widetilde{\rho}_4 h$$

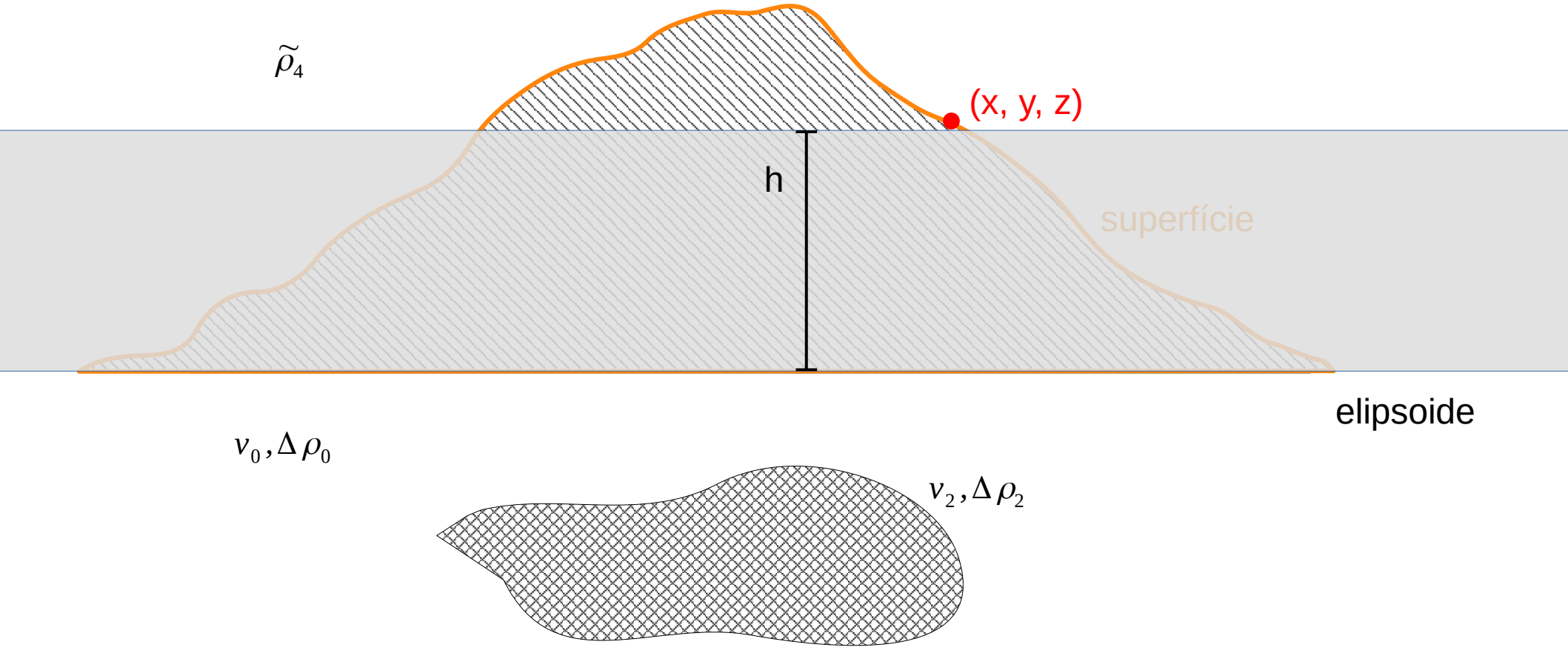


$$\delta g_P = g_P - \gamma_P - 2\pi G \widetilde{\rho}_4 h$$

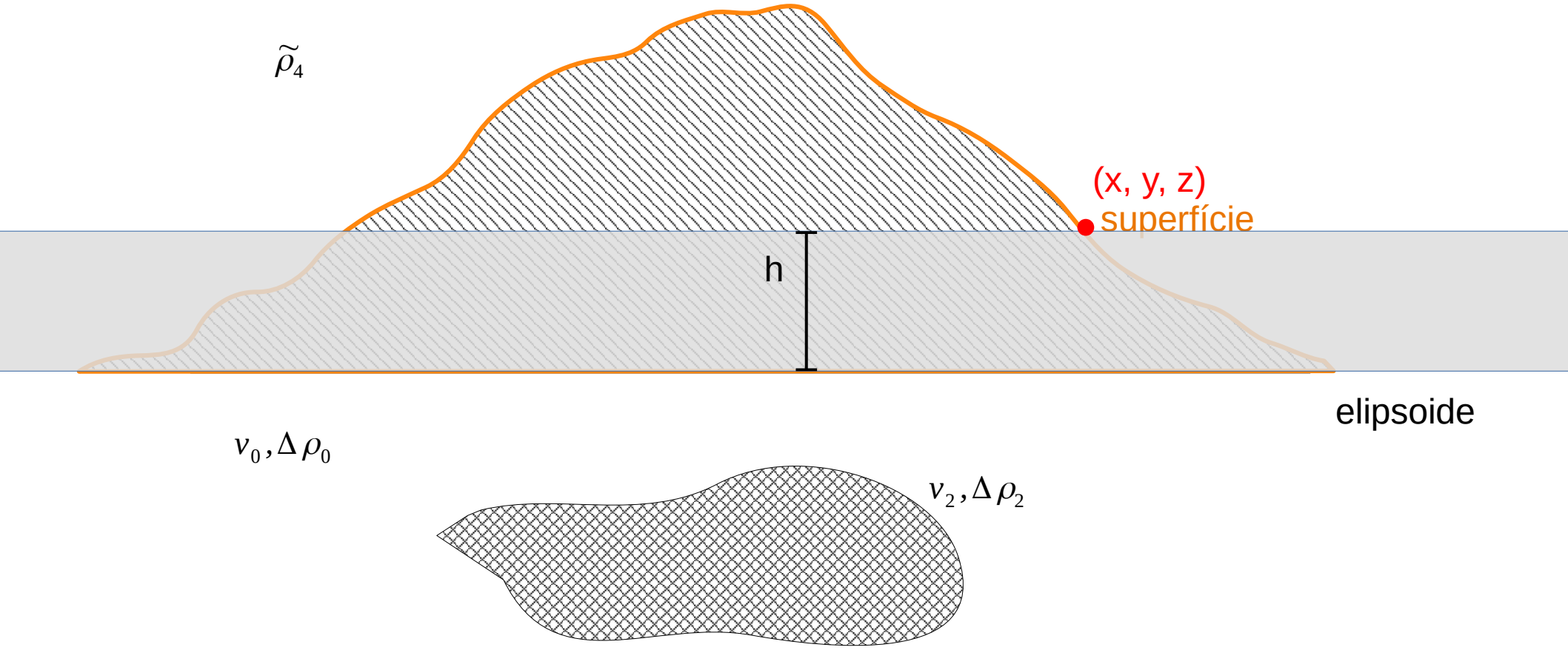


$$\delta g_P = \cancel{G \iiint \partial_z \frac{1}{r} \rho_4 \, dv} + G \iiint \partial_z \frac{1}{r} \Delta\rho_2 \, dv$$

$$\delta g_P = g_P - \gamma_P - 2\pi G \widetilde{\rho}_4 h$$

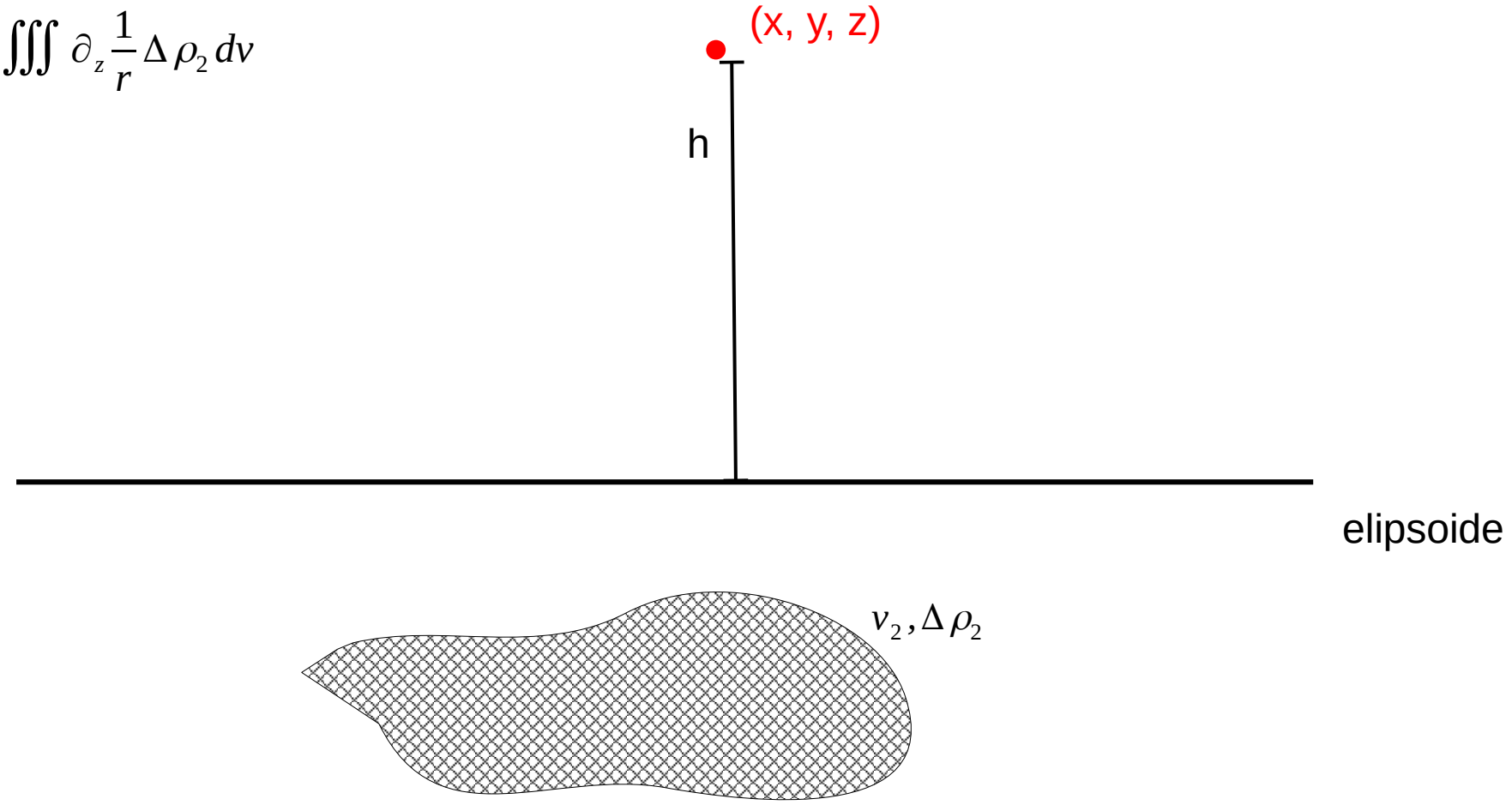


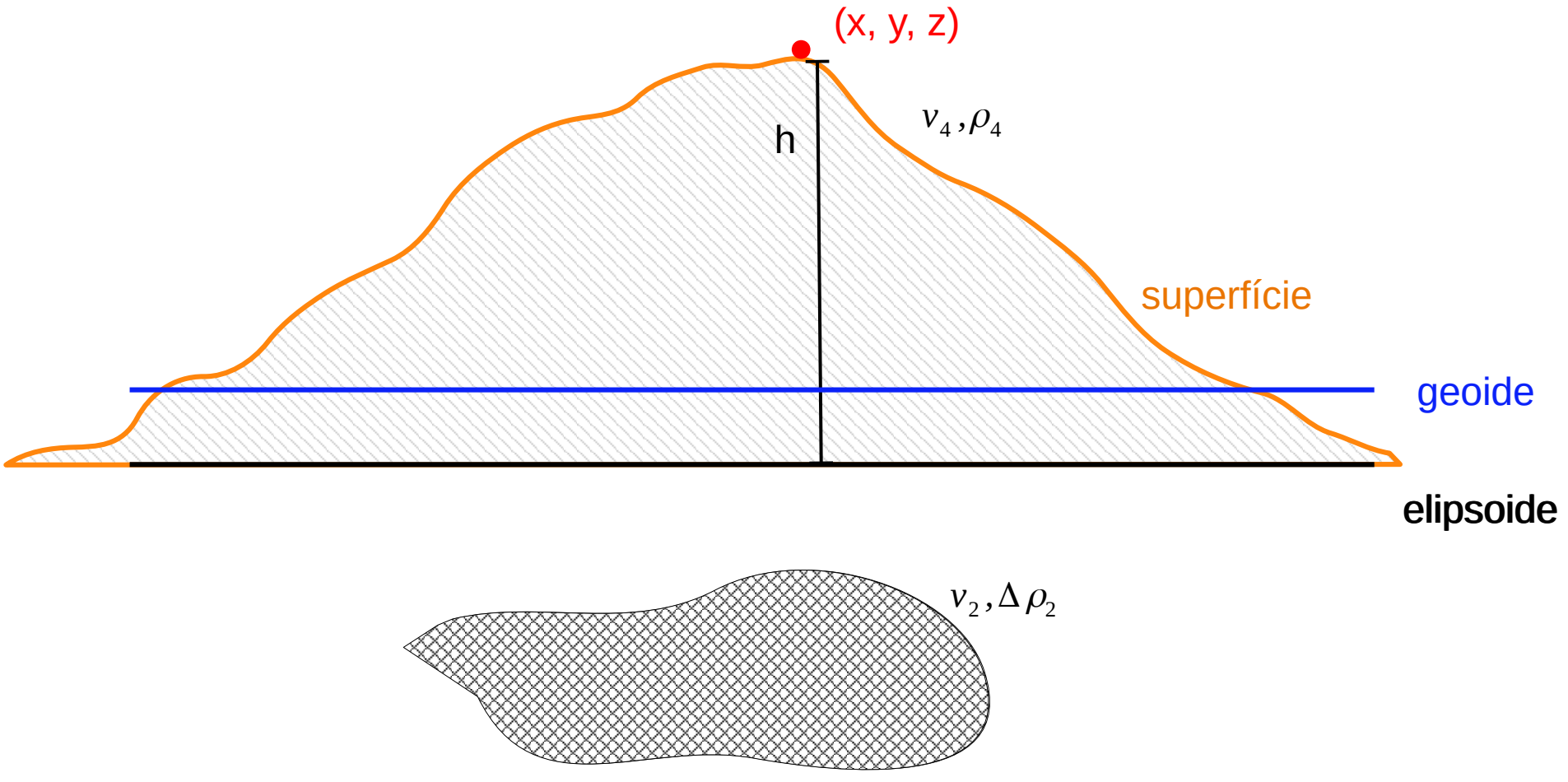
$$\delta g_P = g_P - \gamma_P - 2\pi G \widetilde{\rho}_4 h$$

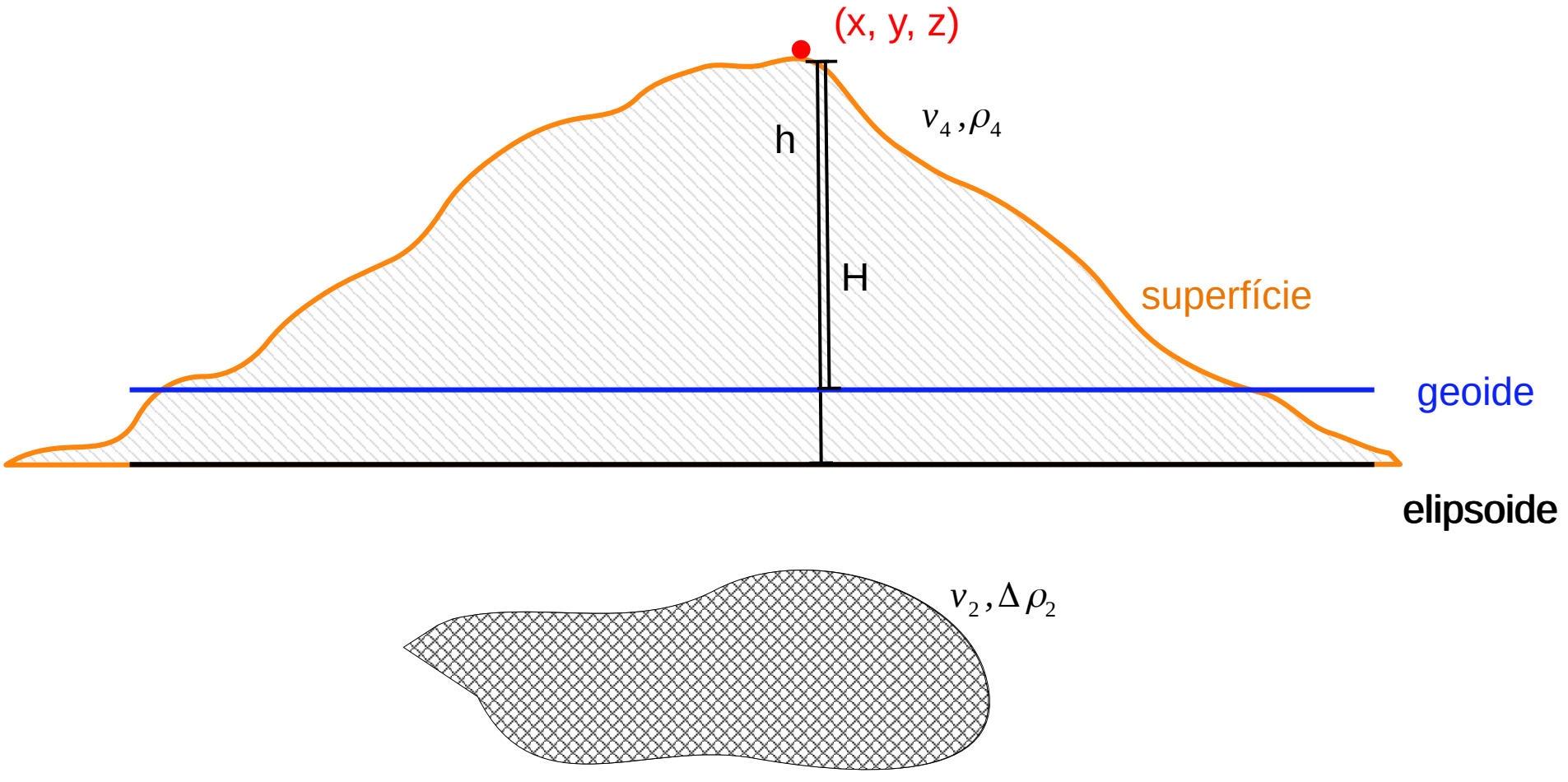


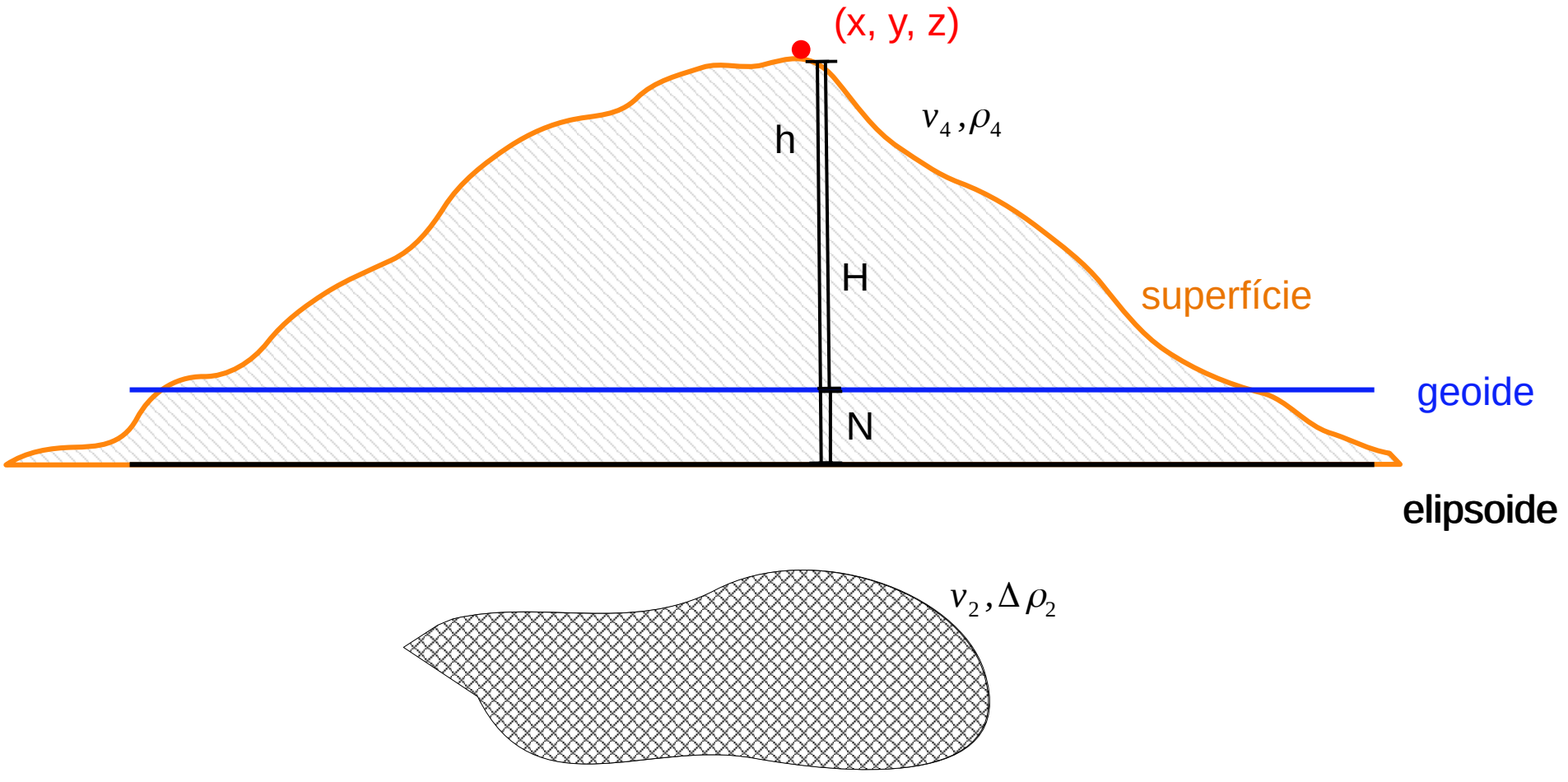
$$\delta g_P = g_P - \gamma_P$$

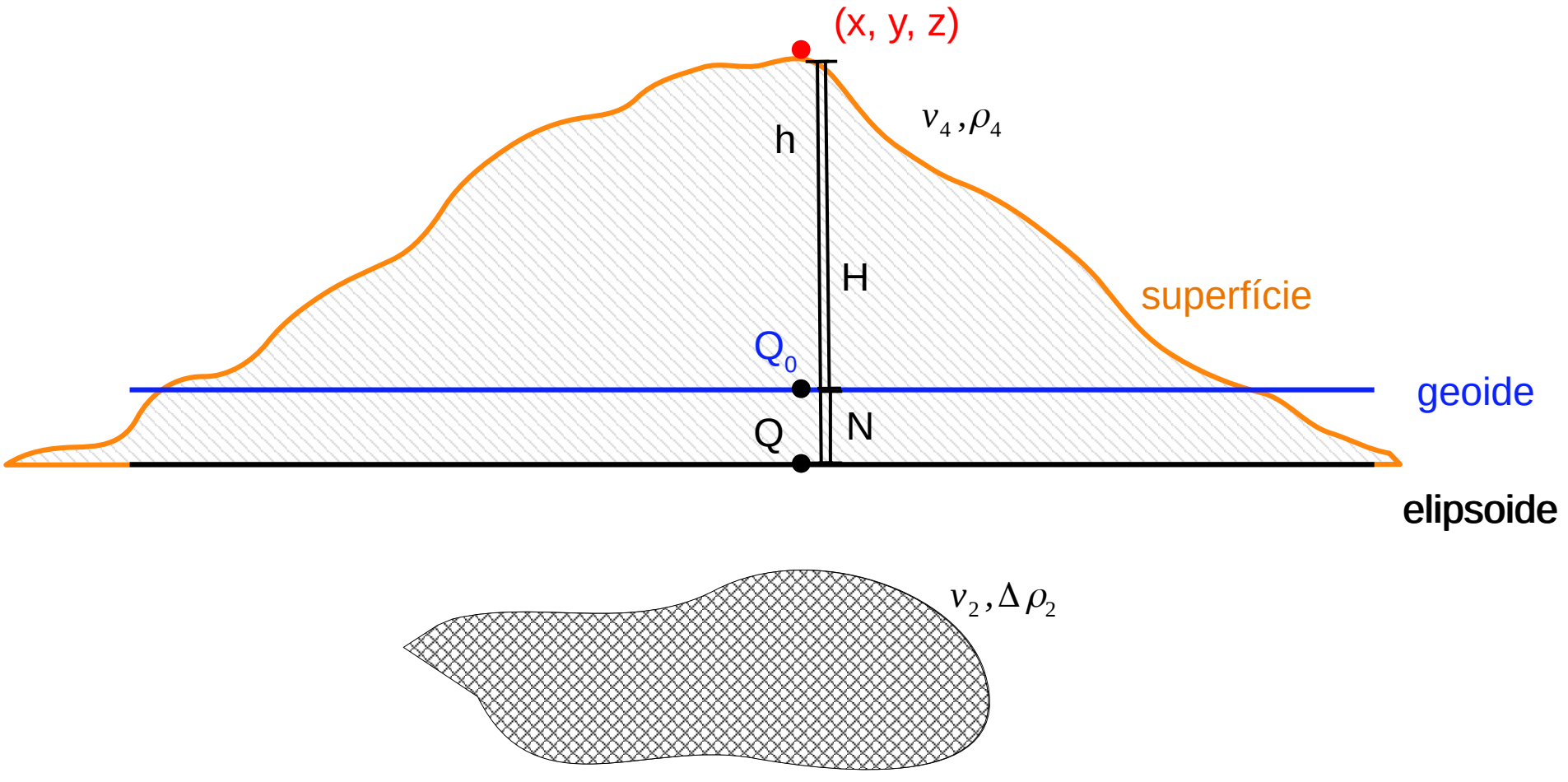
$$\delta g_P = G \iiint \partial_z \frac{1}{r} \Delta\rho_2 \, dv$$



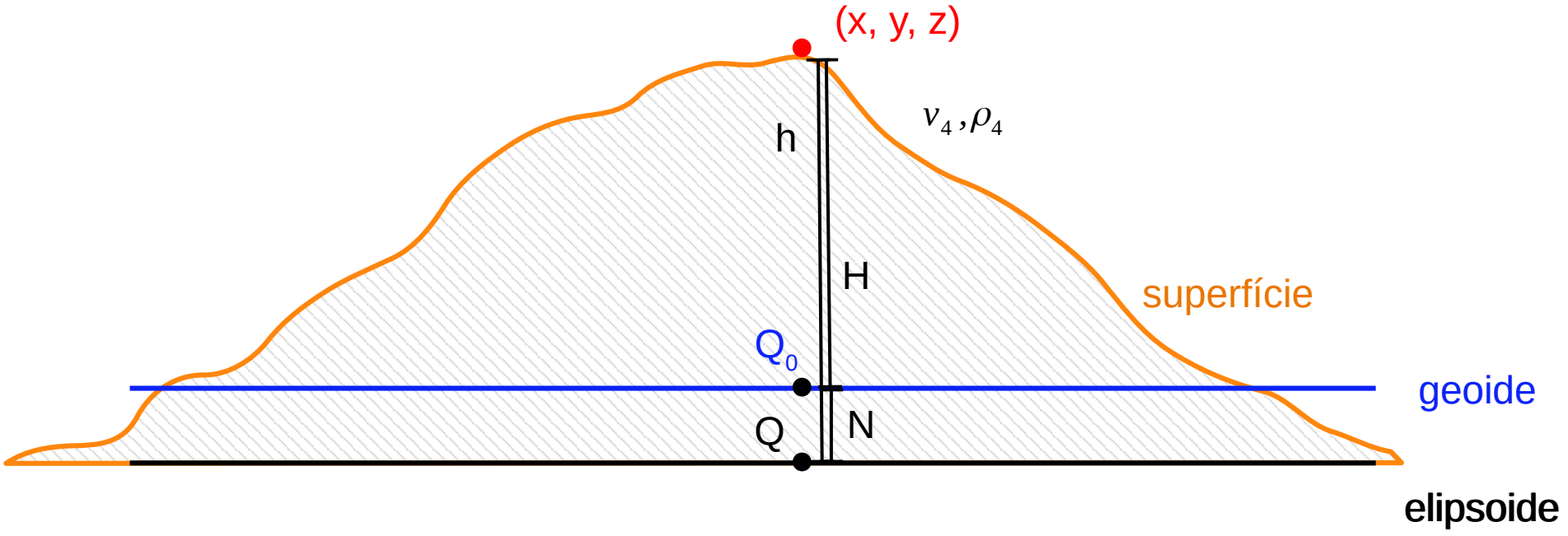

(x, y, z)
h
v_4, ρ_4
superfície
geoide
elipsoide
$v_2, \Delta\rho_2$

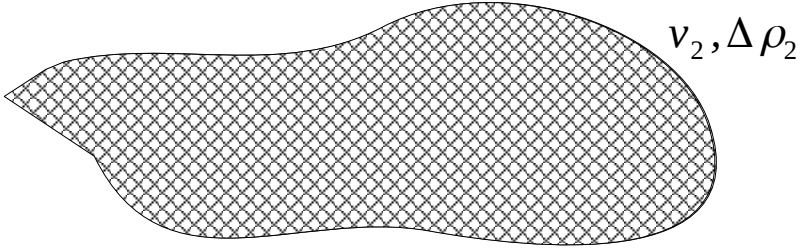

(x, y, z)
h
H
v_4, ρ_4
superfície
geoide
elipsoide
$v_2, \Delta\rho_2$


(x, y, z)
h
v_4, ρ_4
H
superfície
geoide
N
elipsoide
$v_2, \Delta\rho_2$

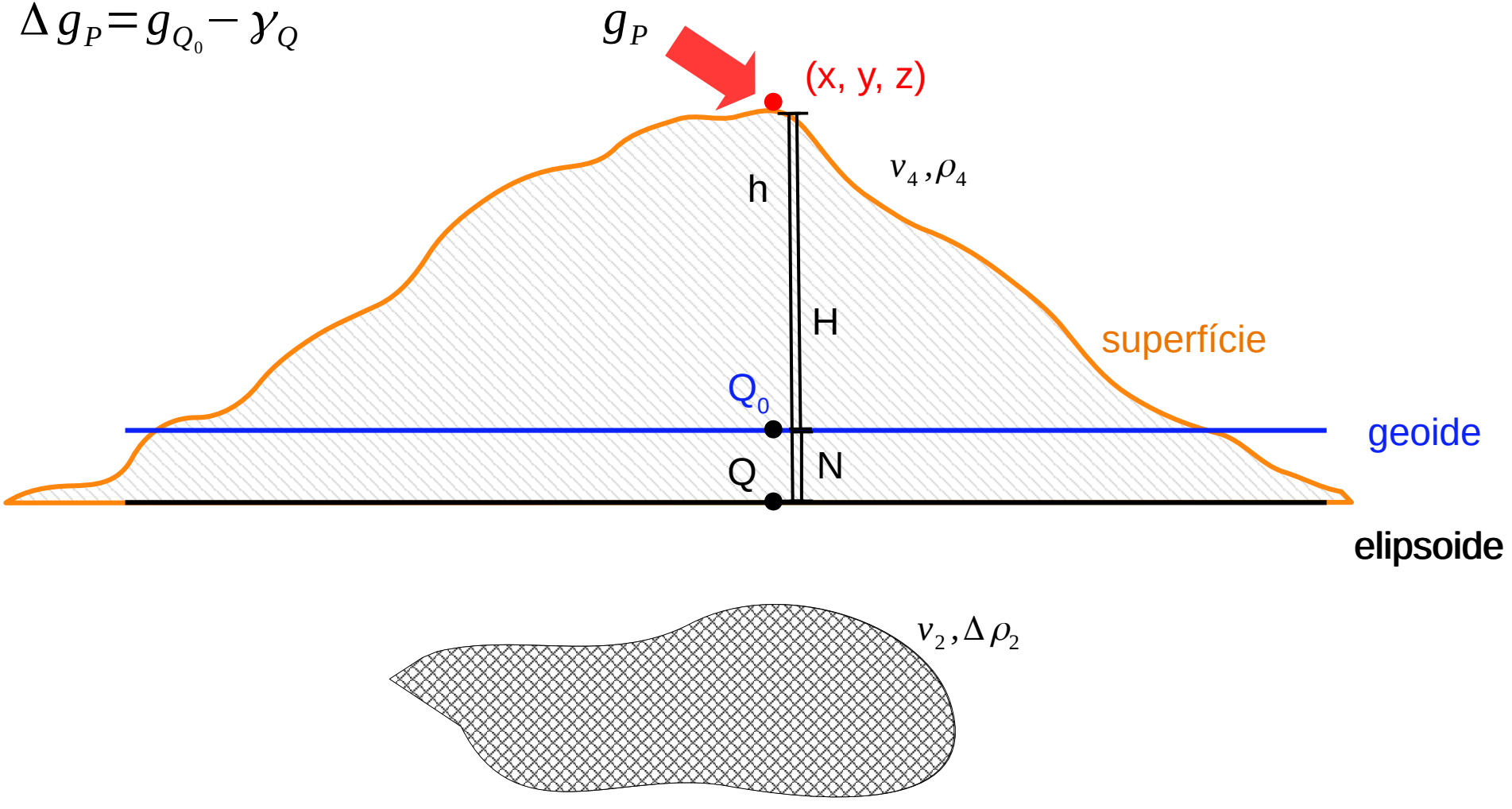

(x, y, z)
h
ν_4, ρ_4
H
superfície
Q_0
geoide
Q
N
elipsoide
$\nu_2, \Delta\rho_2$

$$\Delta g_P = g_{Q_0} - \gamma_Q$$

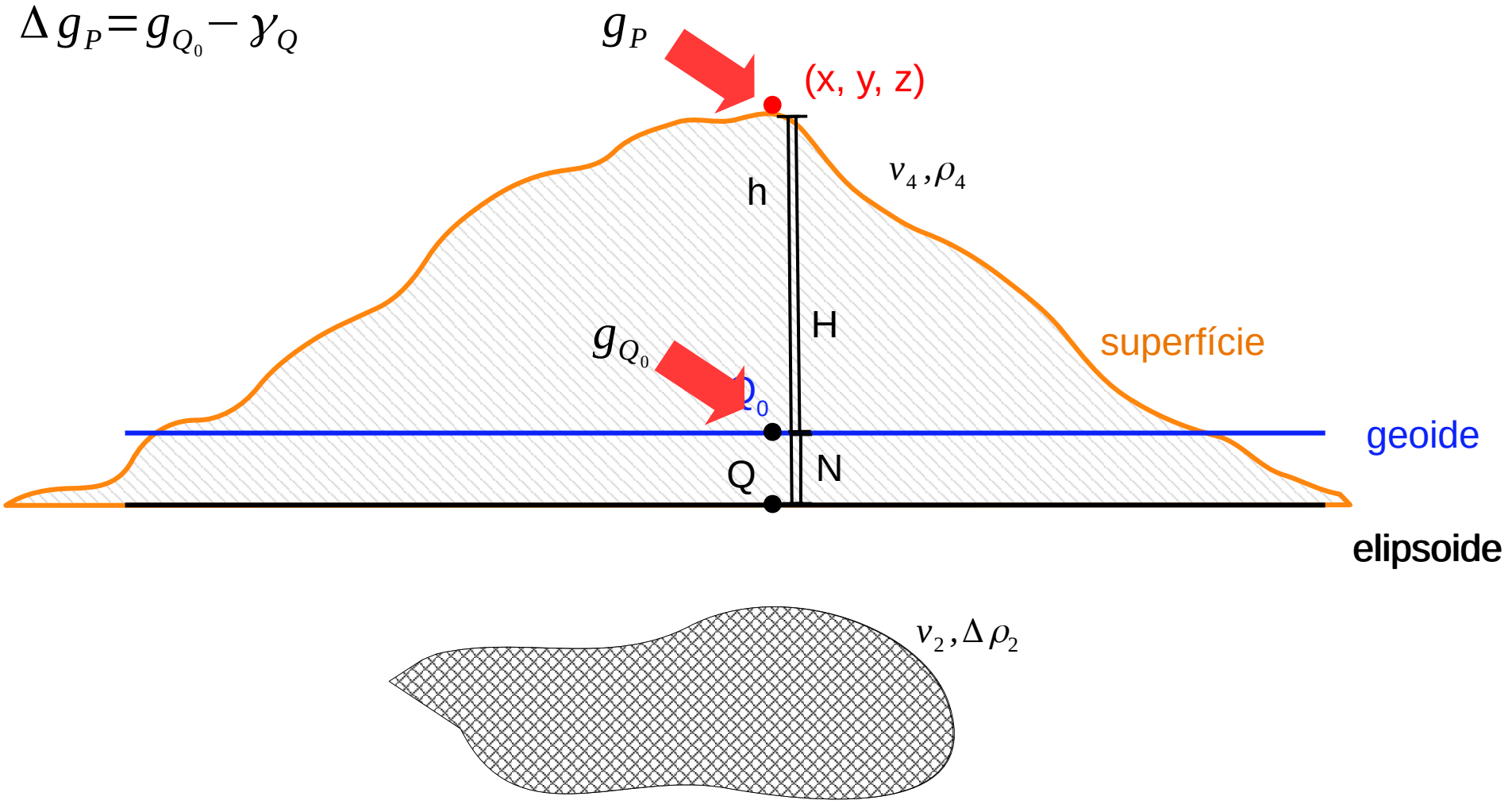




$$\Delta g_P = g_{Q_0} - \gamma_Q$$

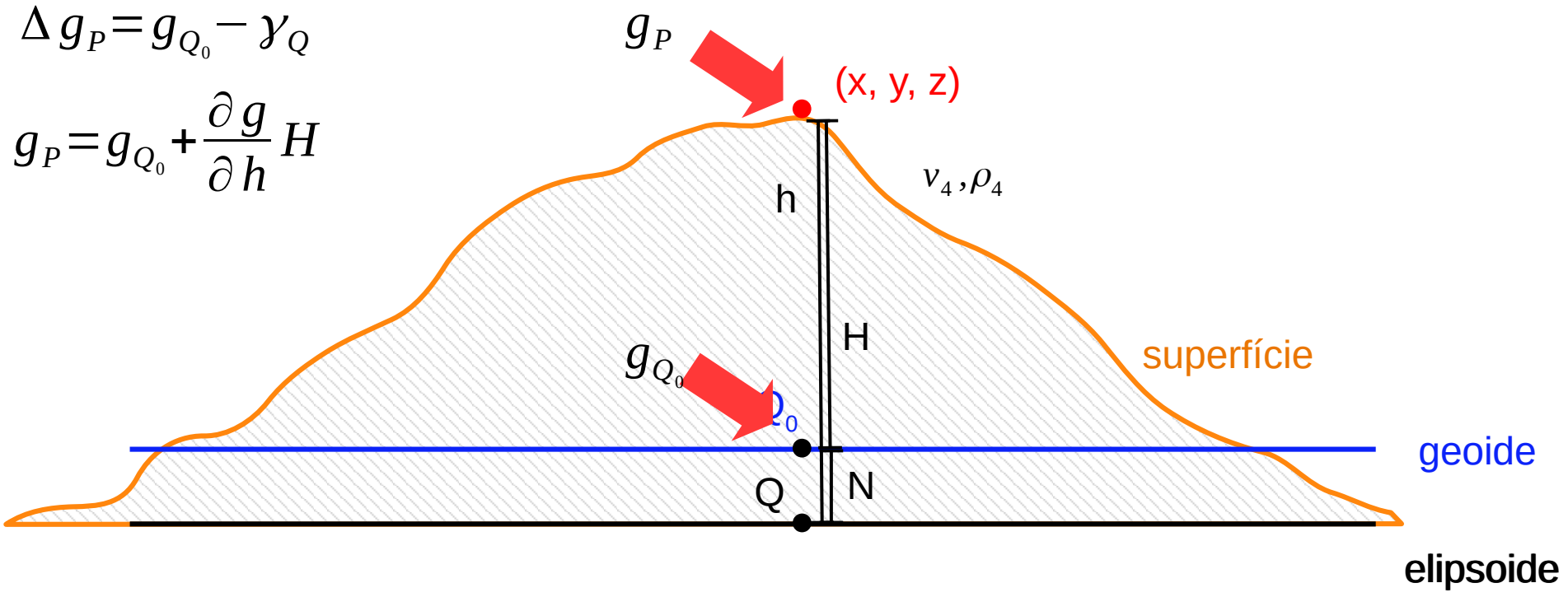


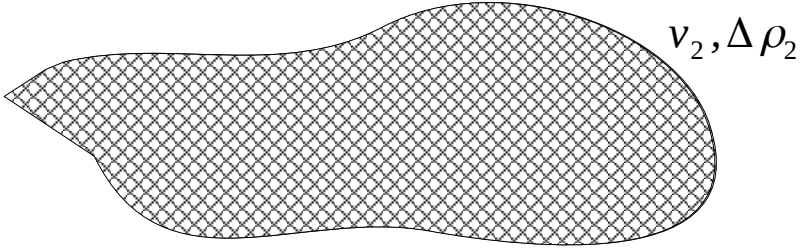
$$\Delta g_P = g_{Q_0} - \gamma_Q$$



$$\Delta g_P = g_{Q_0} - \gamma_Q$$

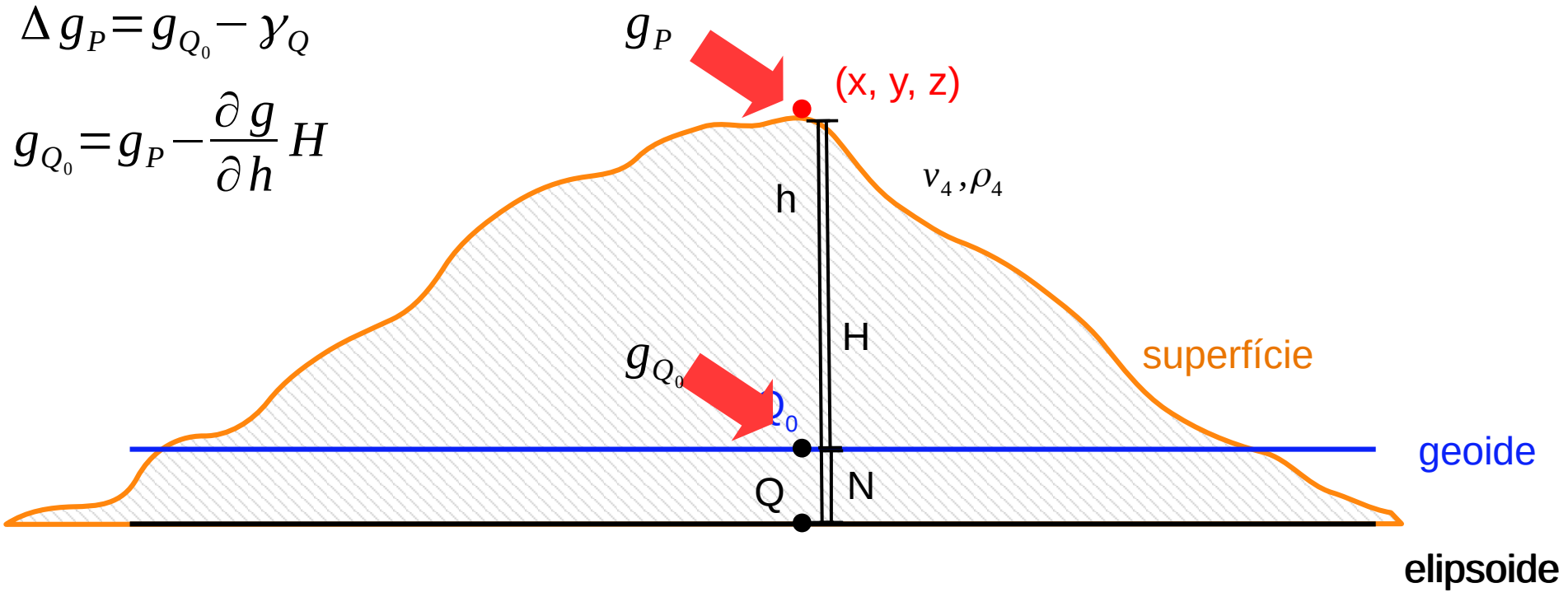
$$g_P = g_{Q_0} + \frac{\partial g}{\partial h} H$$

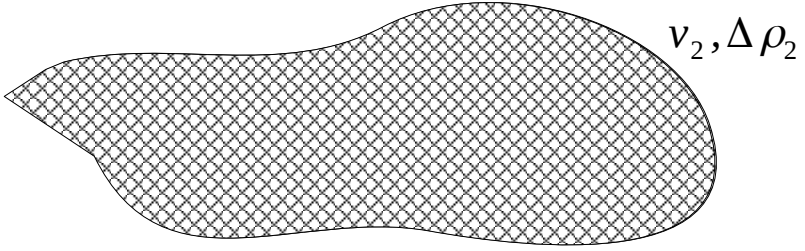




$$\Delta g_P = g_{Q_0} - \gamma_Q$$

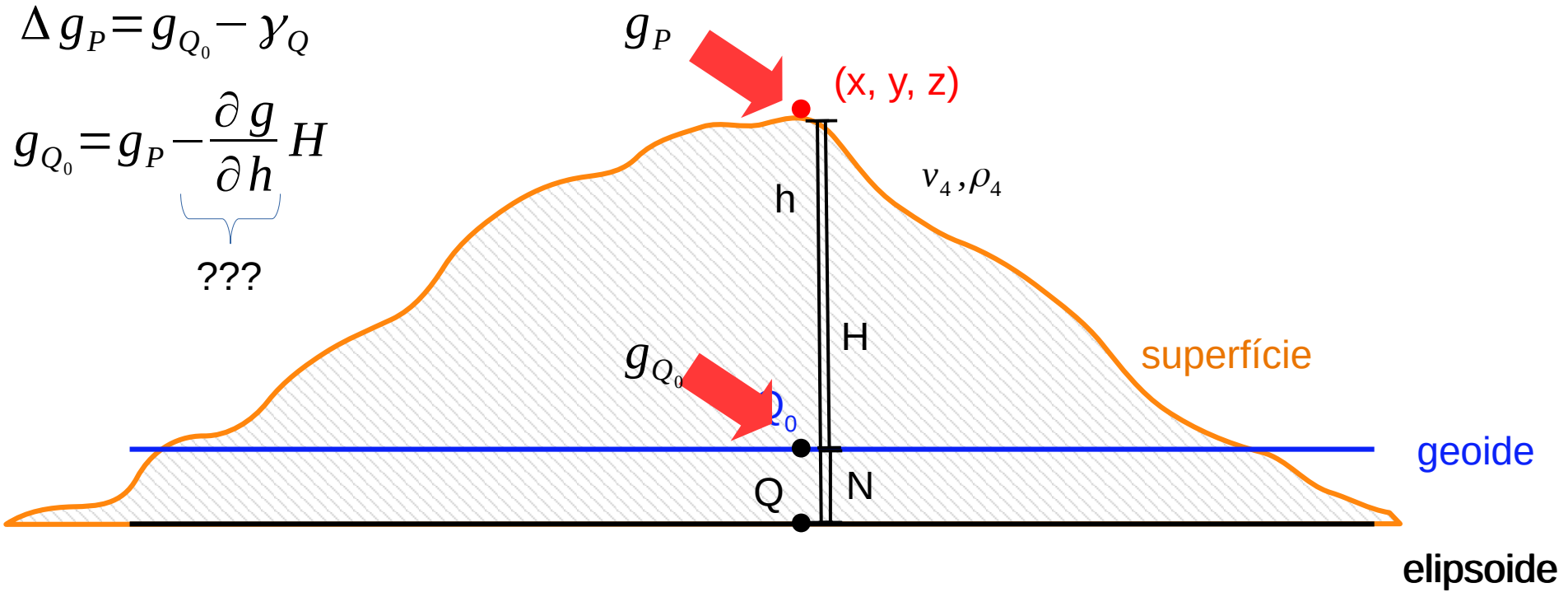
$$g_{Q_0} = g_P - \frac{\partial g}{\partial h} H$$

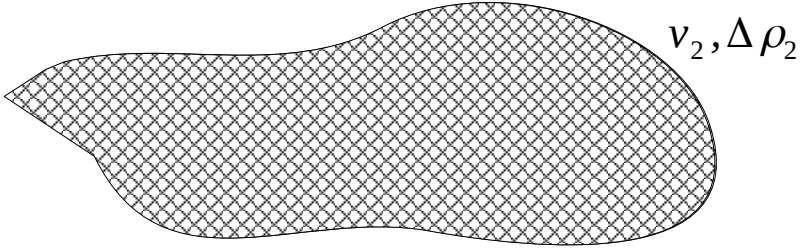




$$\Delta g_P = g_{Q_0} - \gamma_Q$$

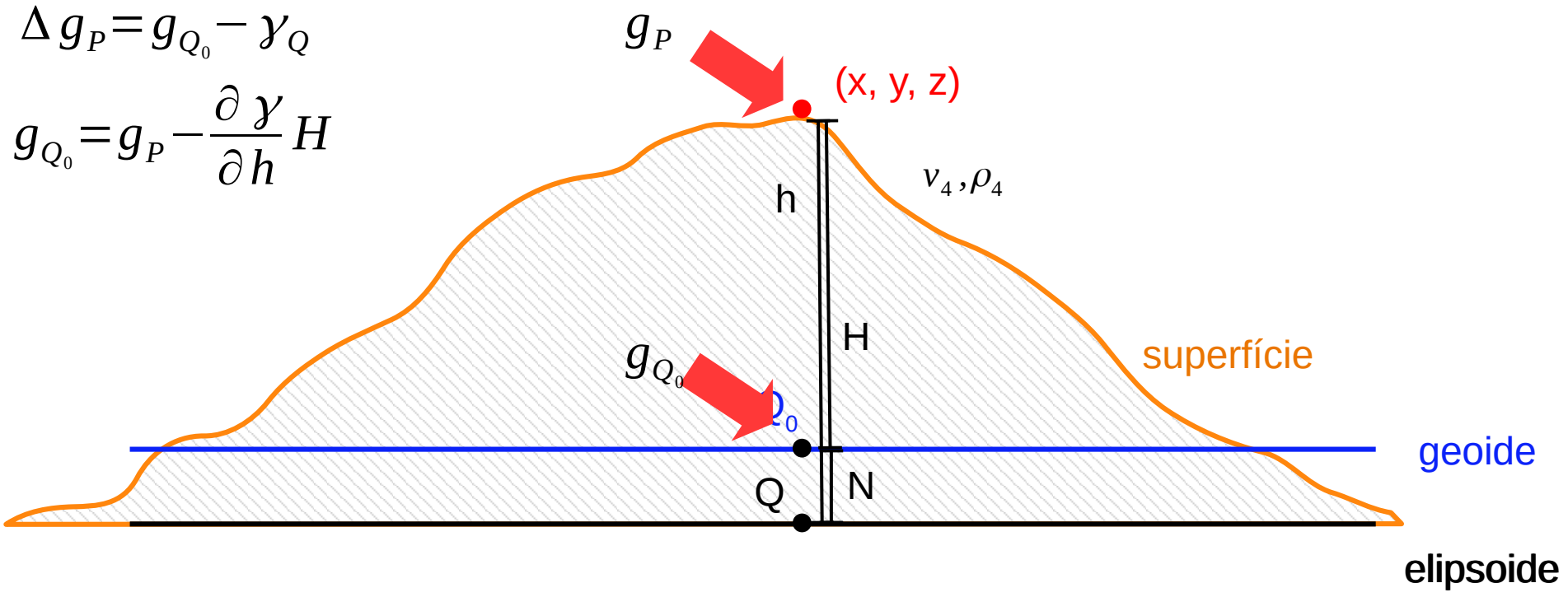
$$g_{Q_0} = g_P - \underbrace{\frac{\partial g}{\partial h}}_{???} H$$

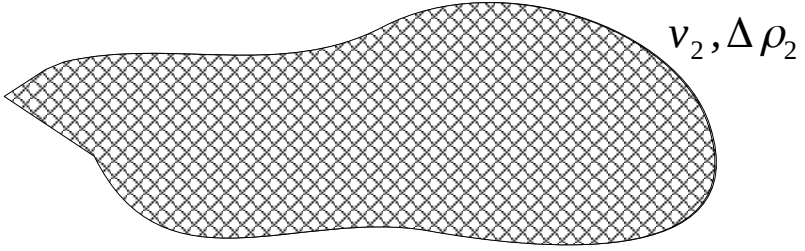




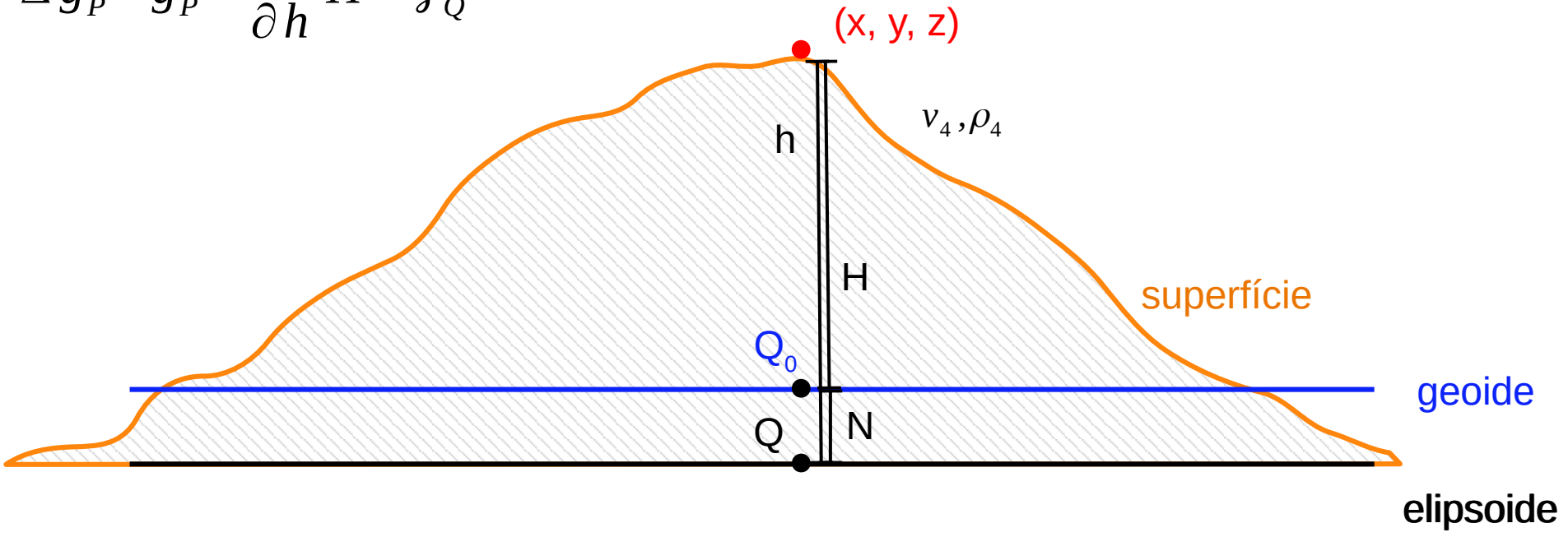
$$\Delta g_P = g_{Q_0} - \gamma_Q$$

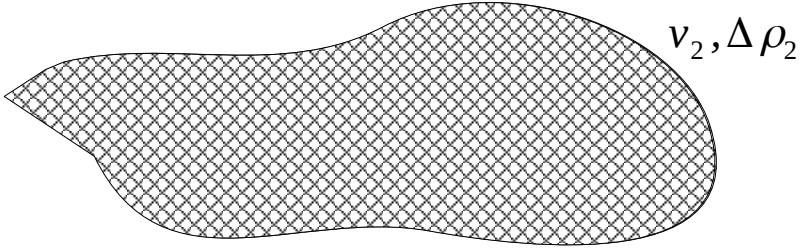
$$g_{Q_0} = g_P - \frac{\partial \gamma}{\partial h} H$$



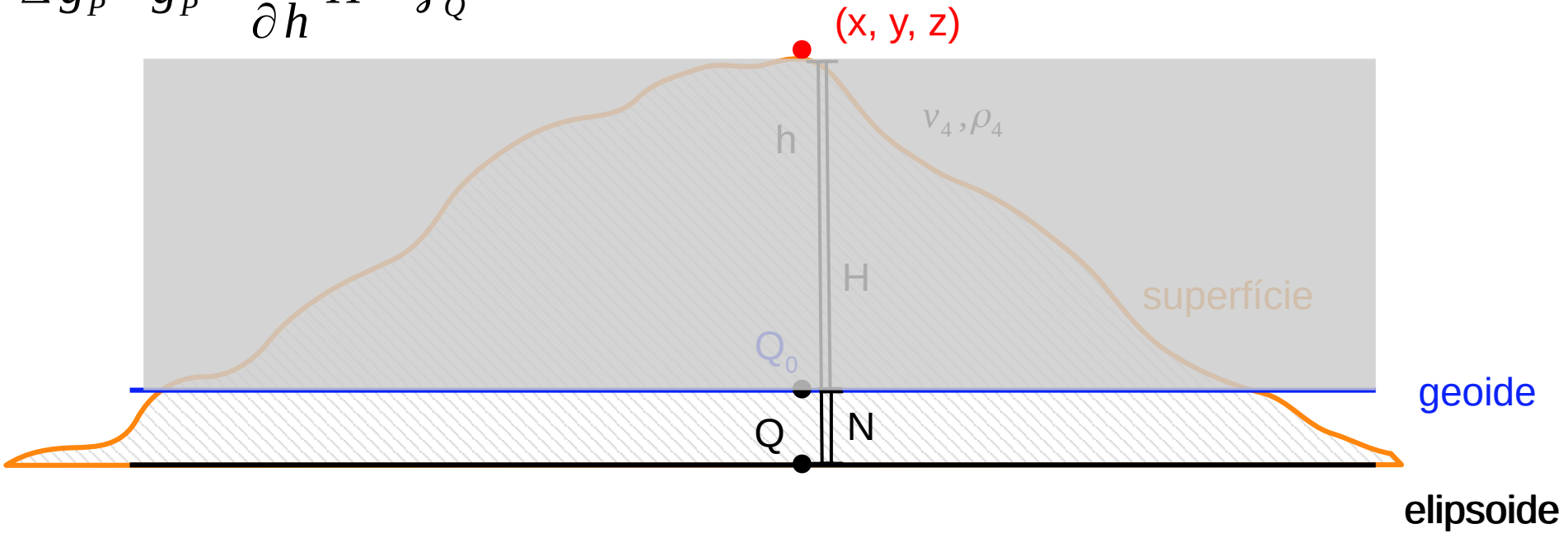


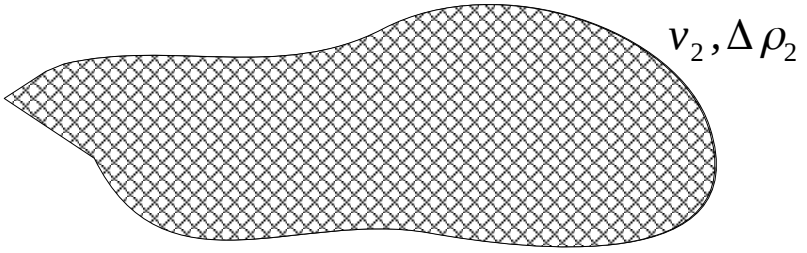
$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} H - \gamma_Q$$



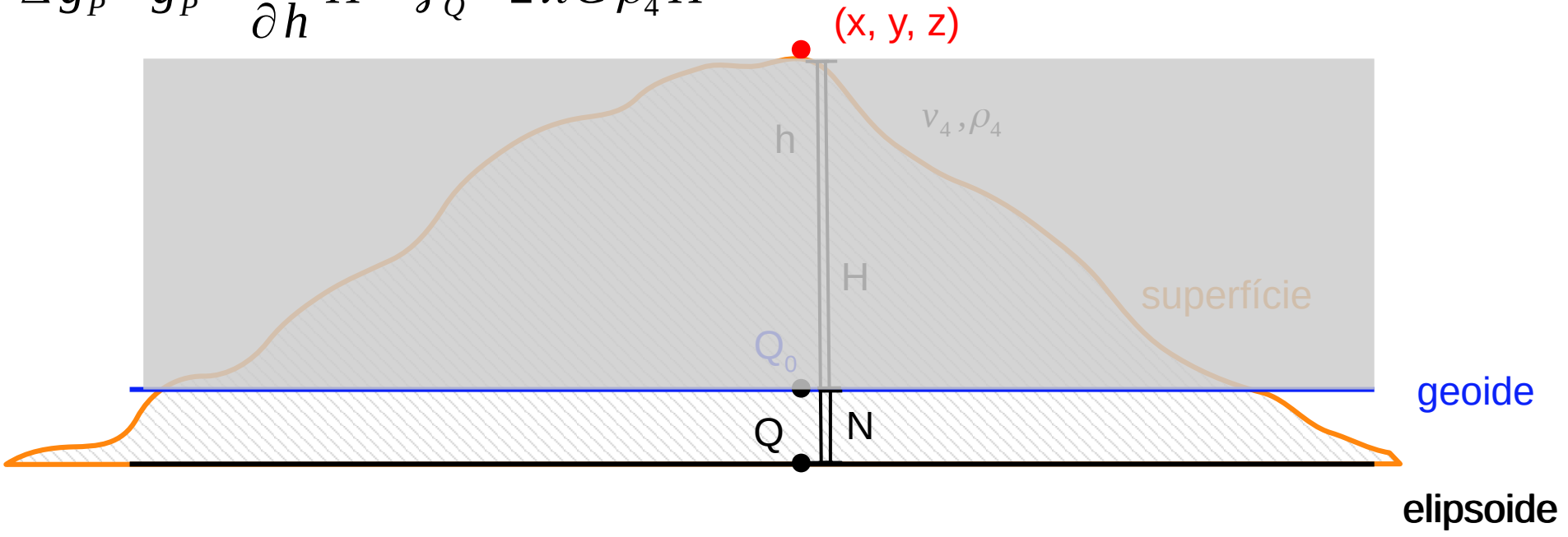


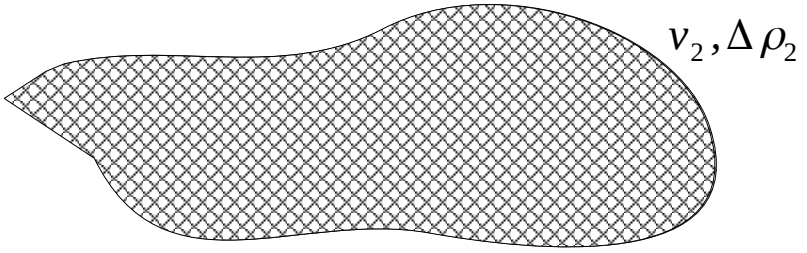
$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} H - \gamma_Q$$



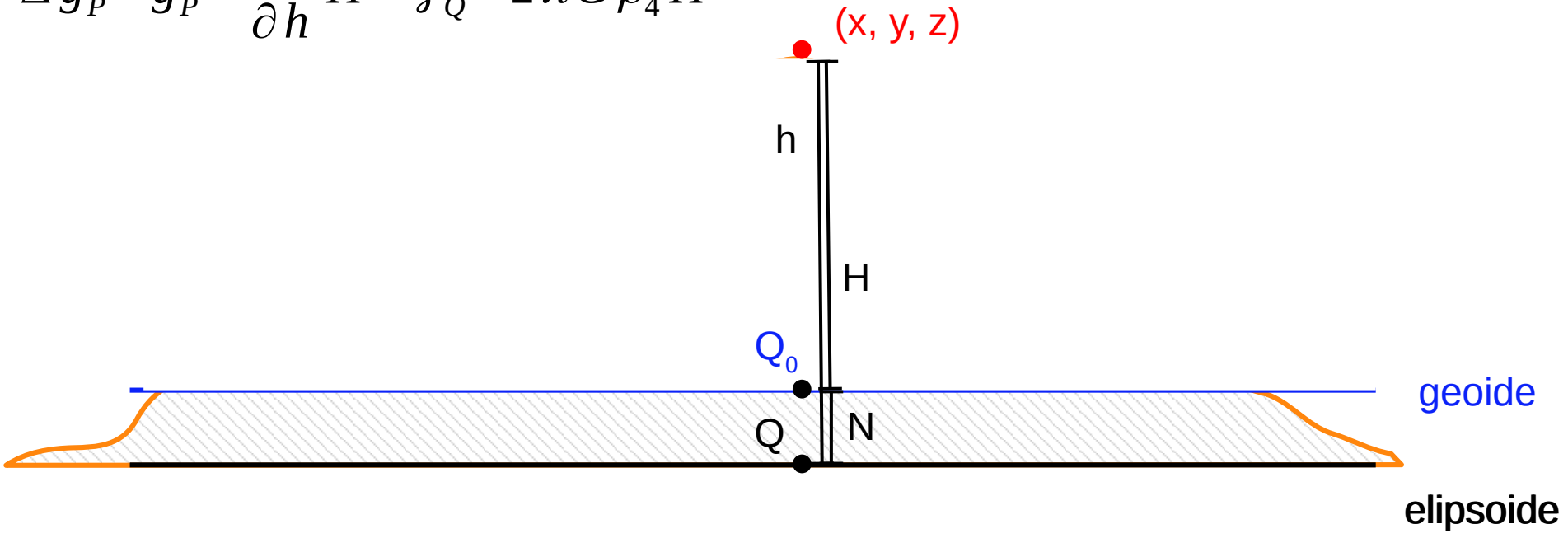


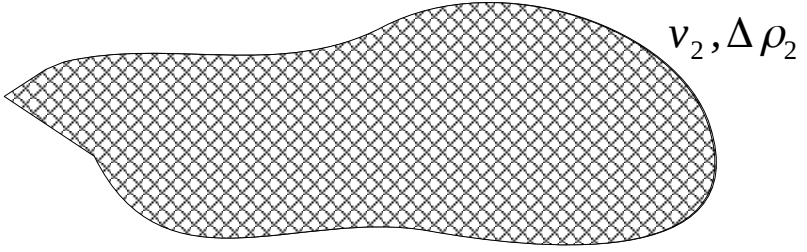
$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} H - \gamma_Q - 2\pi G \tilde{\rho}_4 H$$





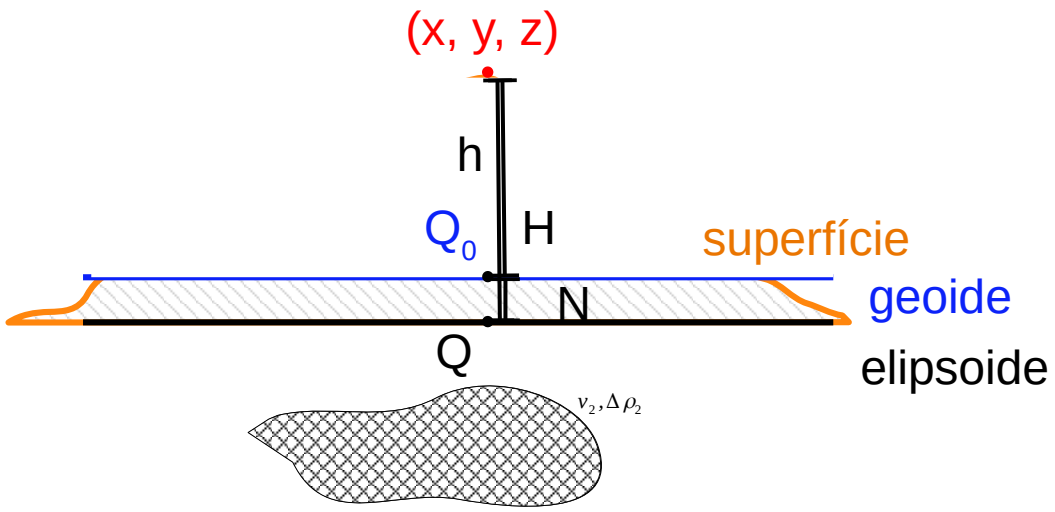
$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} H - \gamma_Q - 2\pi G \tilde{\rho}_4 H$$

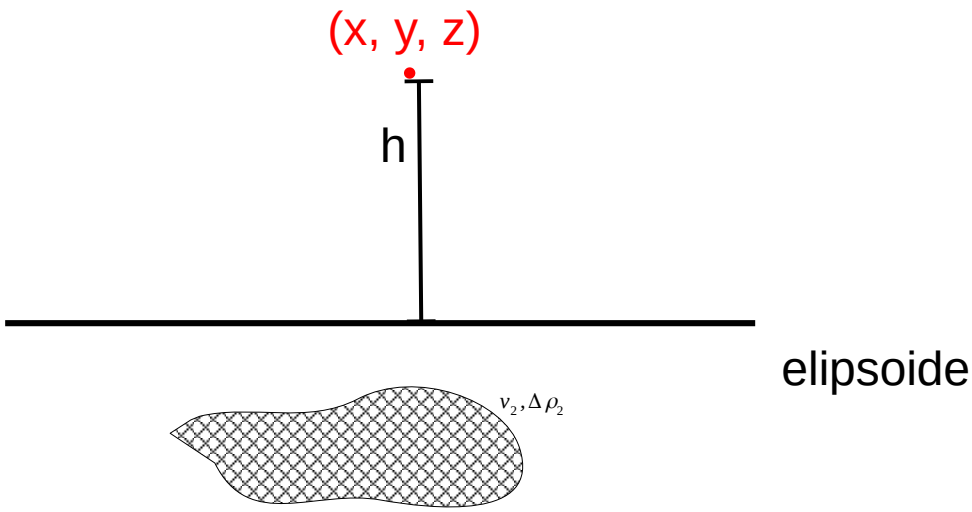




$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} H - \gamma_Q - 2\pi G \tilde{\rho}_4 H$$

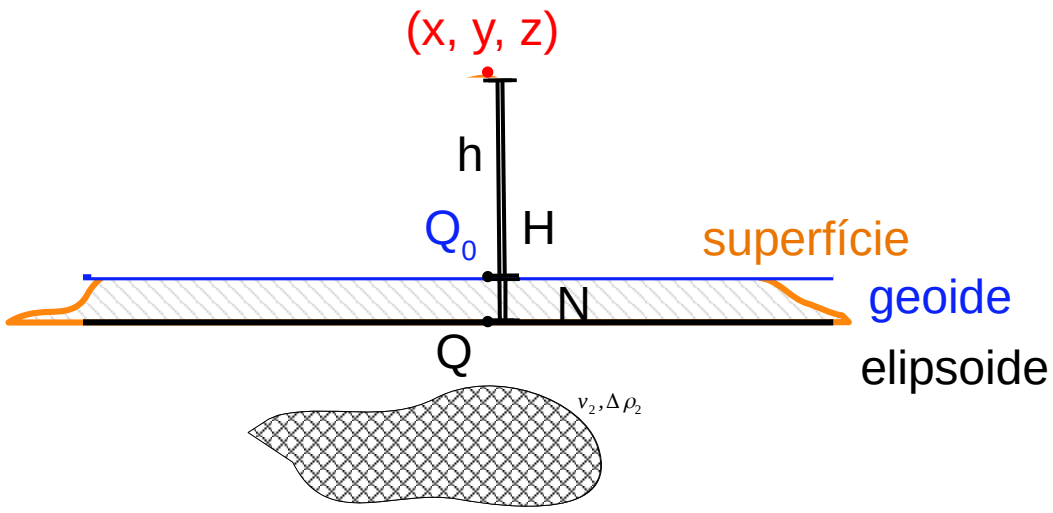
$$\delta g_P = g_P - \gamma_P - 2\pi G \tilde{\rho}_4 h$$

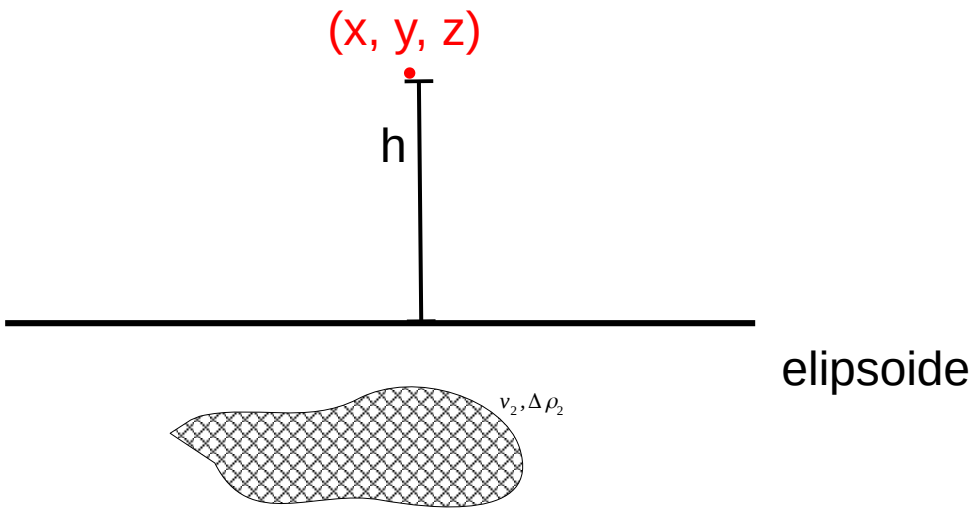




$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} H - \gamma_Q - 2\pi G \tilde{\rho}_4 H$$

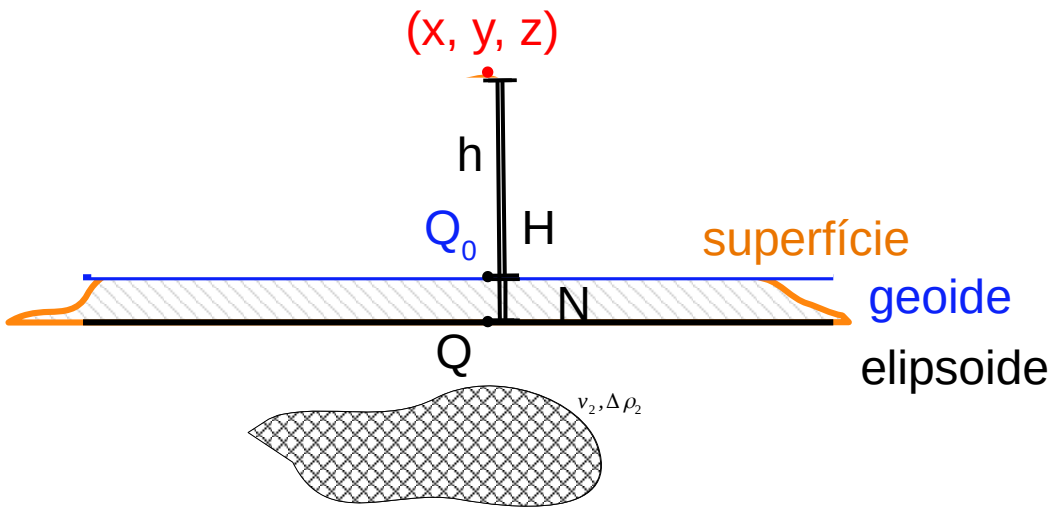
$$\delta g_P = g_P - \gamma_P - 2\pi G \tilde{\rho}_4 h$$

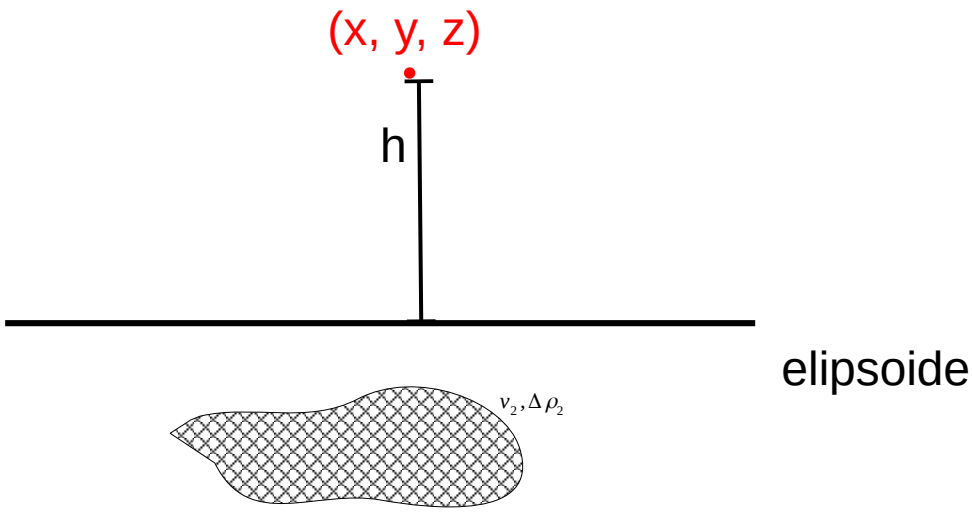




$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} H - \gamma_Q - 2\pi G \tilde{\rho}_4 H$$

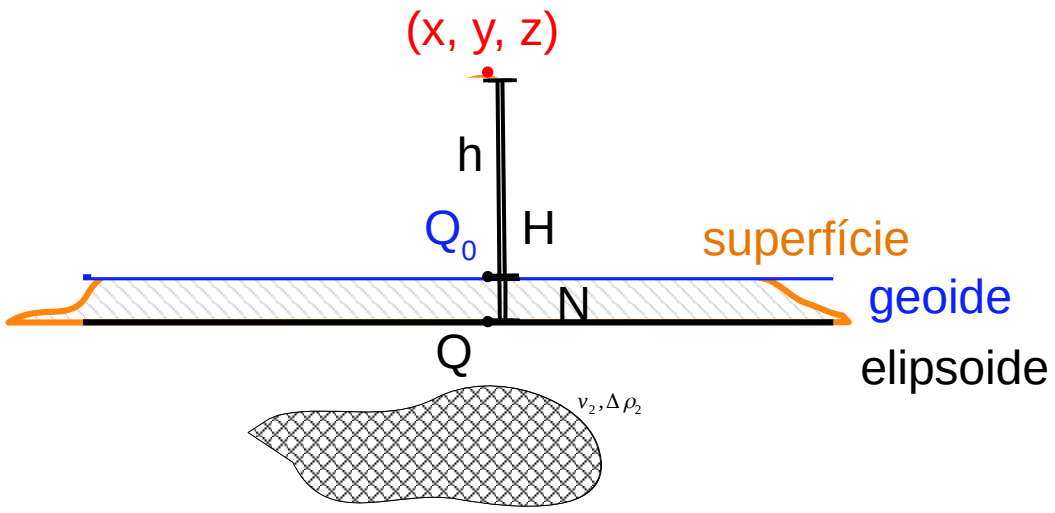
$$\delta g_P = g_P - \gamma_P - 2\pi G \tilde{\rho}_4 h$$

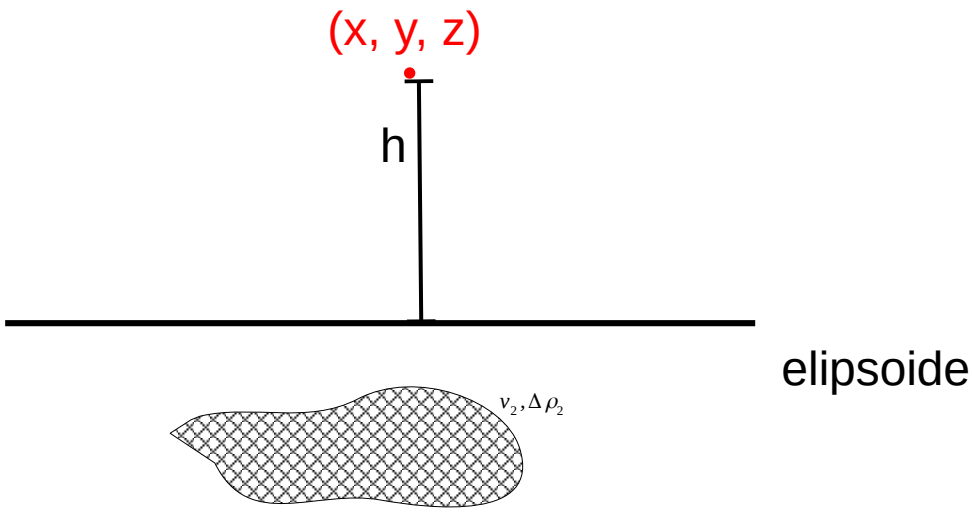




$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} H - \gamma_Q - 2\pi G \tilde{\rho}_4 H$$

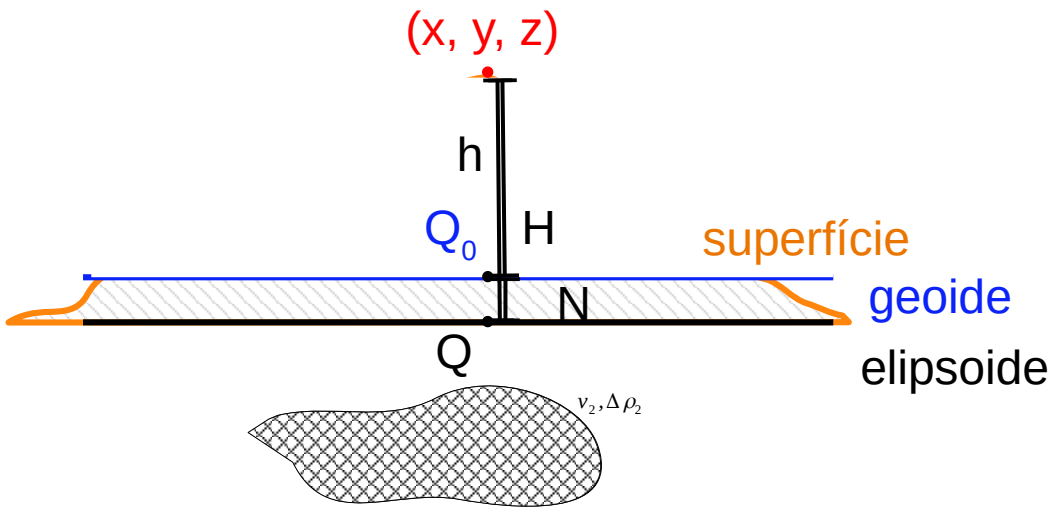
$$\delta g_P = g_P - \gamma_P - 2\pi G \tilde{\rho}_4 h$$

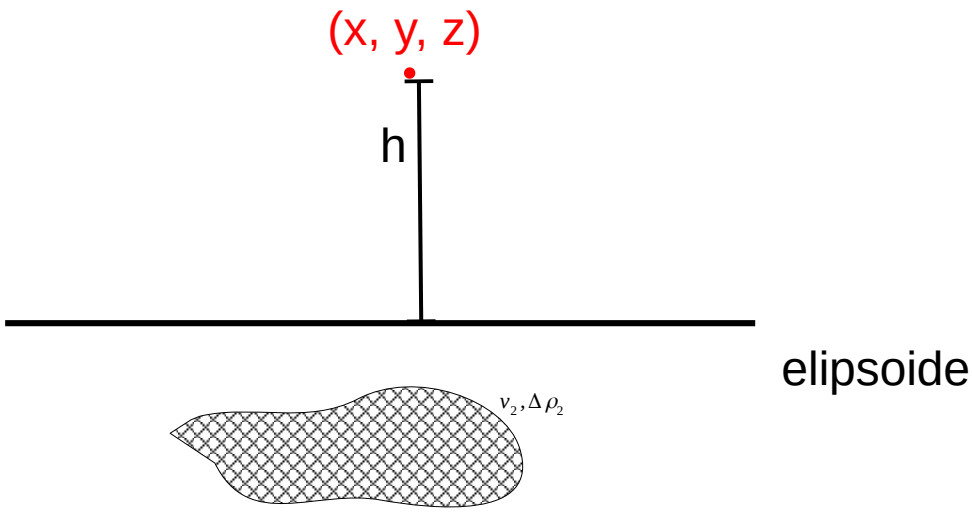




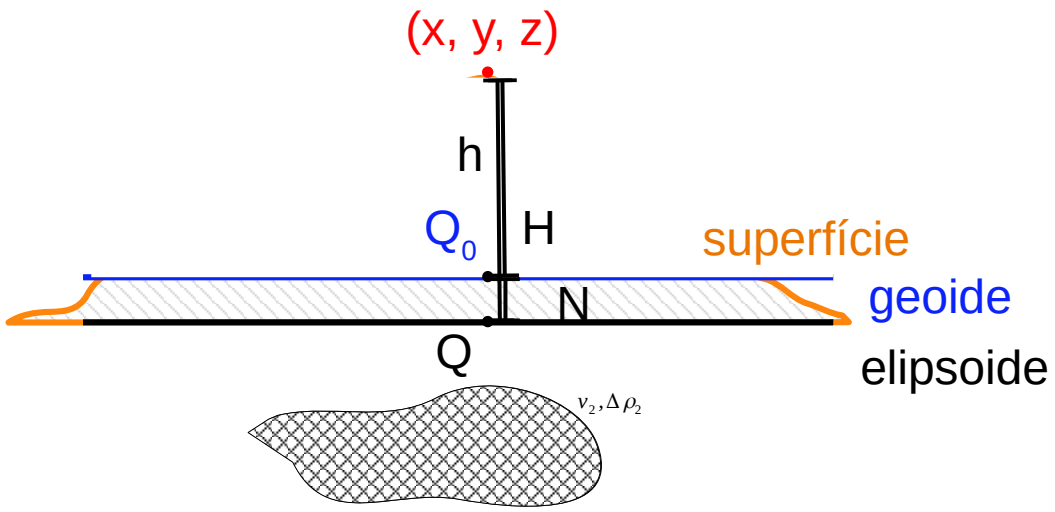
$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} H - \gamma_Q - 2\pi G \tilde{\rho}_4 H$$

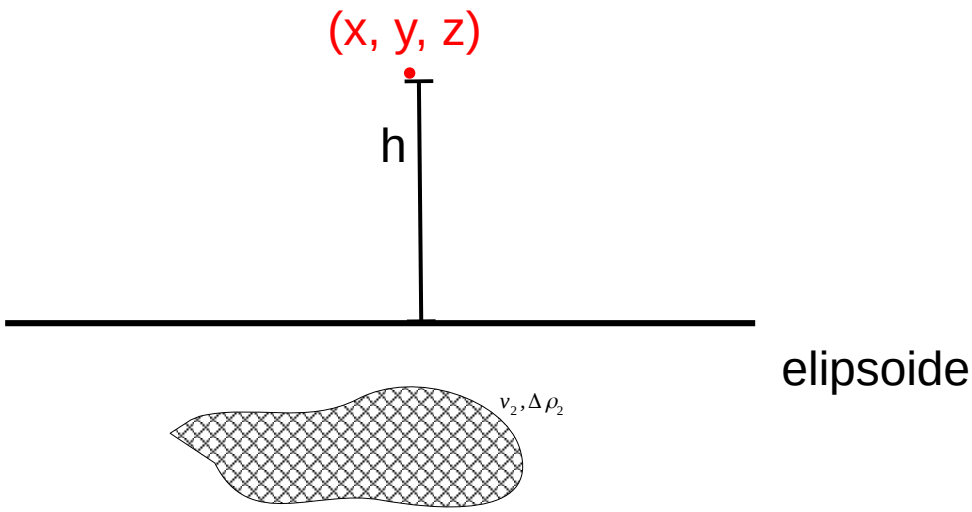
$$\delta g_P = g_P - \gamma_P - 2\pi G \tilde{\rho}_4 h$$





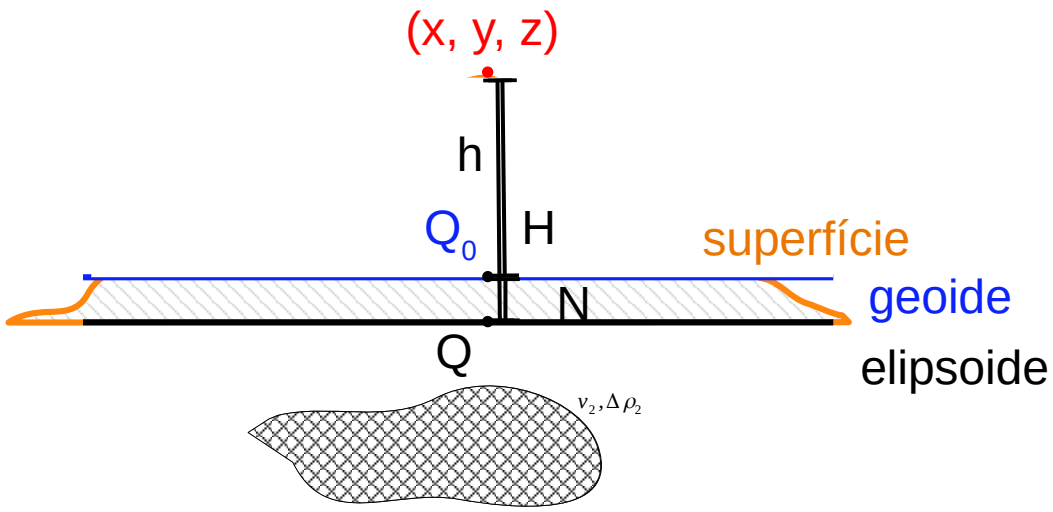
$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h}(h-N) - \gamma_Q - 2\pi G\tilde{\rho}_4(h-N) \qquad \delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h$$

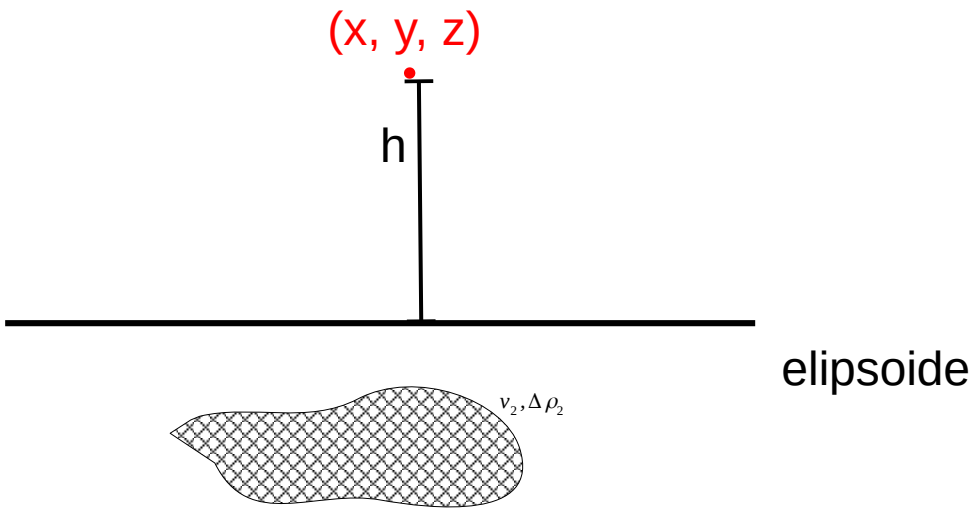




$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} h + \frac{\partial \gamma}{\partial h} N - \gamma_Q - 2\pi G \tilde{\rho}_4 h + 2\pi G \tilde{\rho}_4 N$$

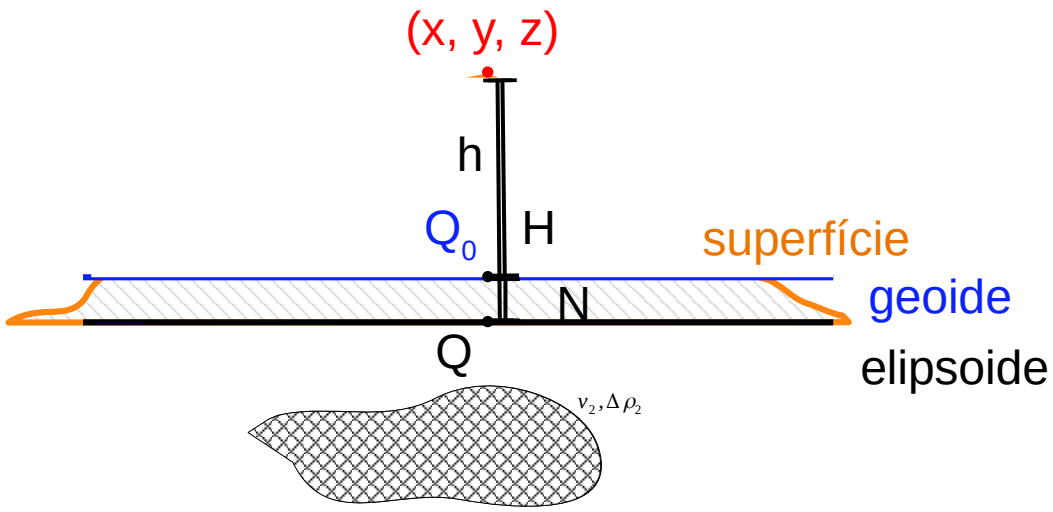
$$\delta g_P = g_P - \gamma_P - 2\pi G \tilde{\rho}_4 h$$

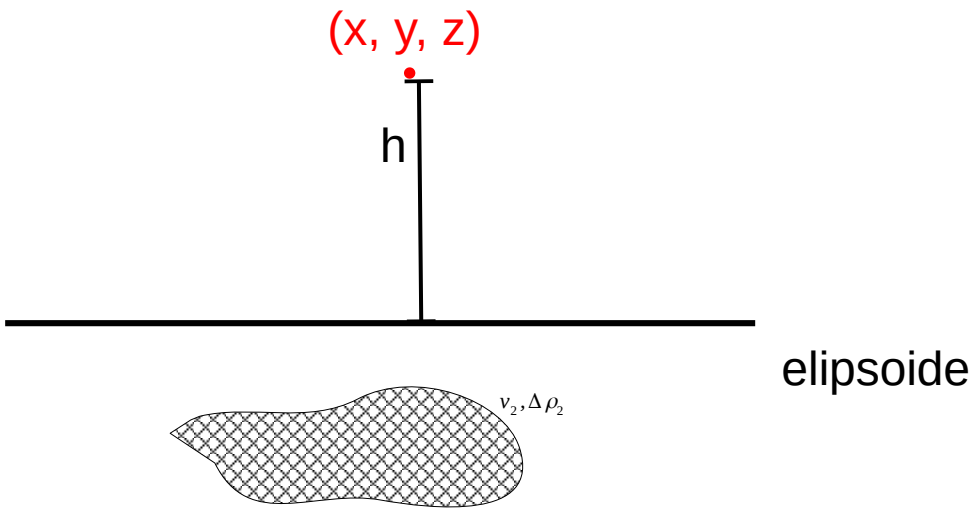




$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} h + \frac{\partial \gamma}{\partial h} N - \gamma_Q - 2\pi G \tilde{\rho}_4 h + 2\pi G \tilde{\rho}_4 N$$

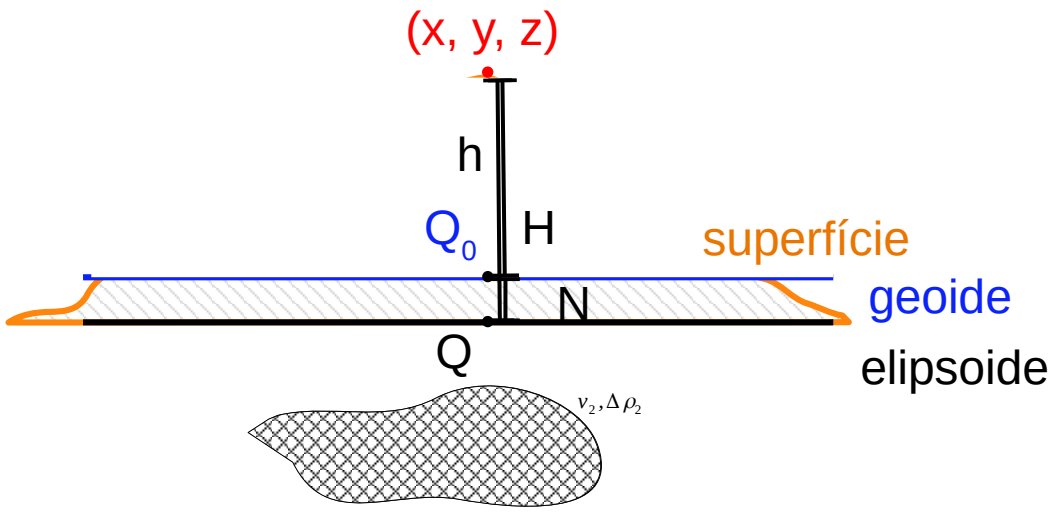
$$\delta g_P = g_P - \gamma_P - 2\pi G \tilde{\rho}_4 h$$

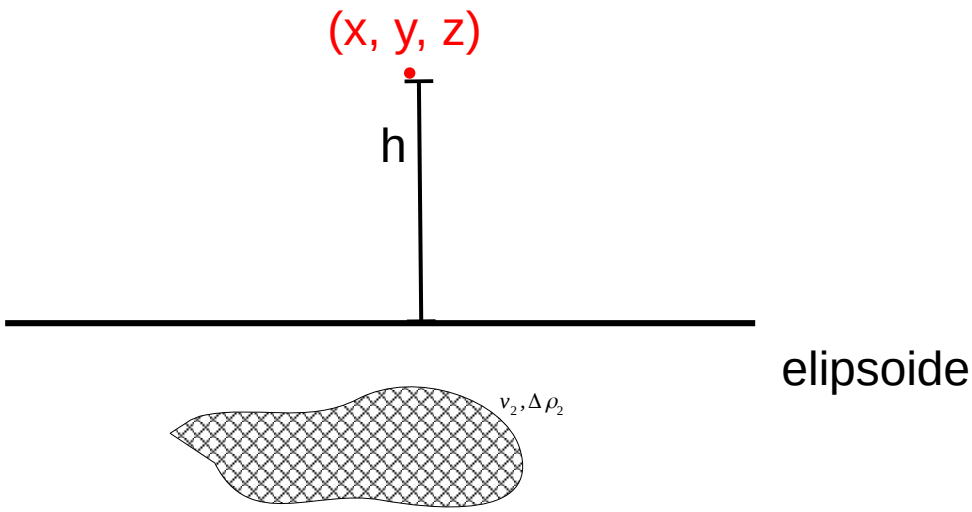




$$\Delta g_P = g_P - \frac{\partial \gamma}{\partial h} h - \gamma_Q - 2\pi G \tilde{\rho}_4 h + \frac{\partial \gamma}{\partial h} N + 2\pi G \tilde{\rho}_4 N$$

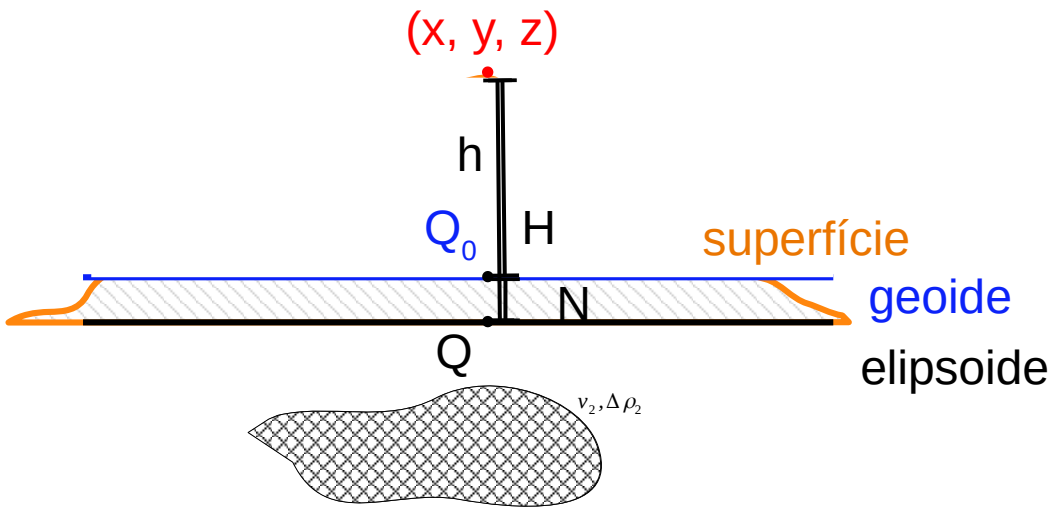
$$\delta g_P = g_P - \gamma_P - 2\pi G \tilde{\rho}_4 h$$

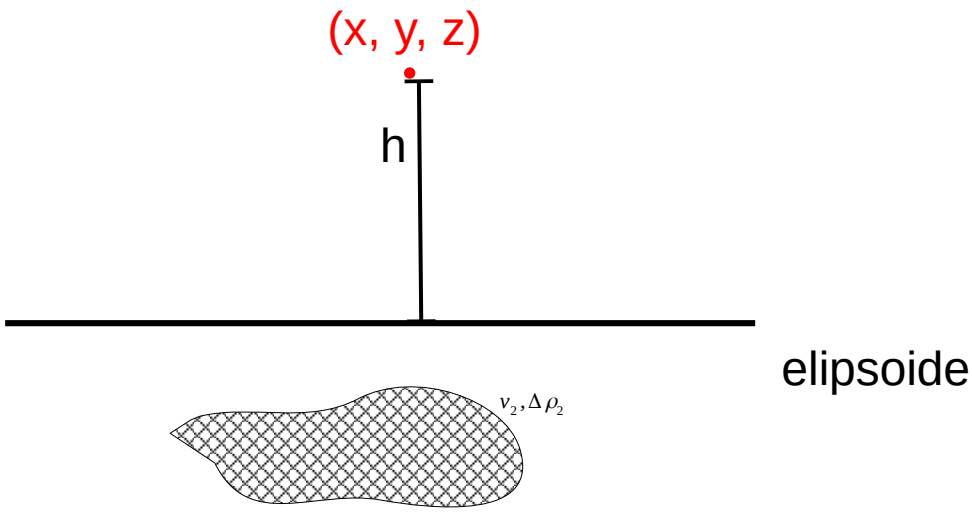




$$\Delta g_P = g_P \underbrace{- \frac{\partial \gamma}{\partial h} h - \gamma_Q}_{-\gamma_P} - 2\pi G \tilde{\rho}_4 h + \frac{\partial \gamma}{\partial h} N + 2\pi G \tilde{\rho}_4 N$$

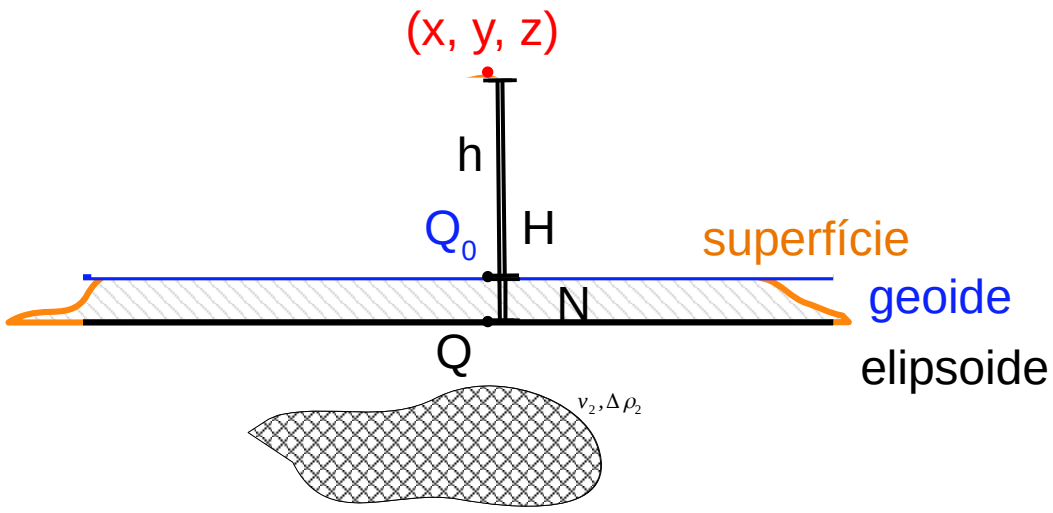
$$\delta g_P = g_P - \gamma_P - 2\pi G \tilde{\rho}_4 h$$

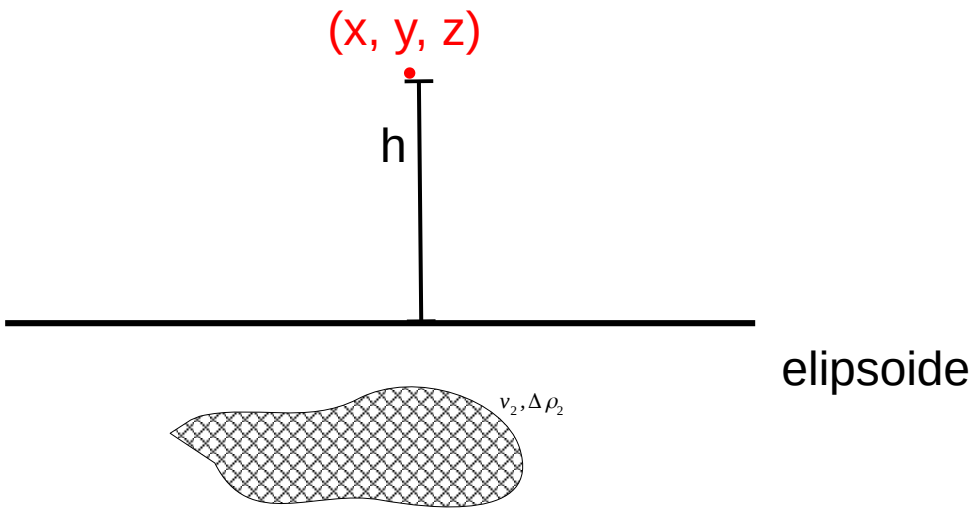




$$\Delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h + \frac{\partial \gamma}{\partial h} N + 2\pi G\tilde{\rho}_4 N$$

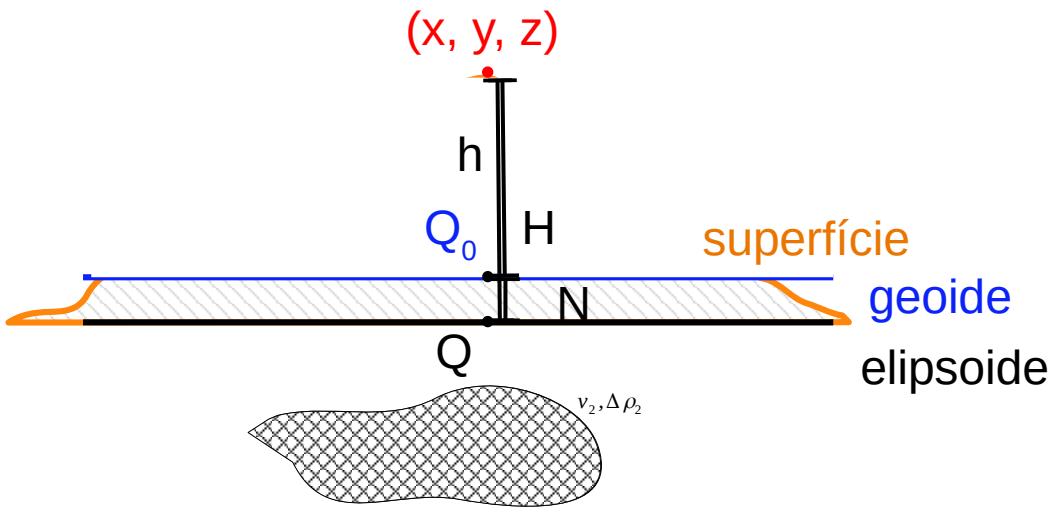
$$\delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h$$

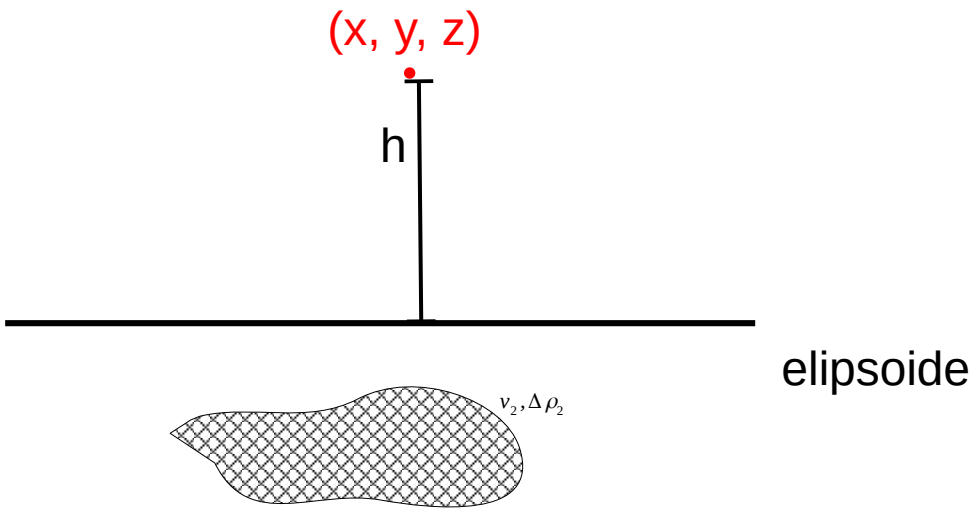




$$\Delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h + \underbrace{\frac{\partial \gamma}{\partial h}}_{-0.3086\,\frac{mGal}{m}} N + 2\pi G\tilde{\rho}_4 N$$

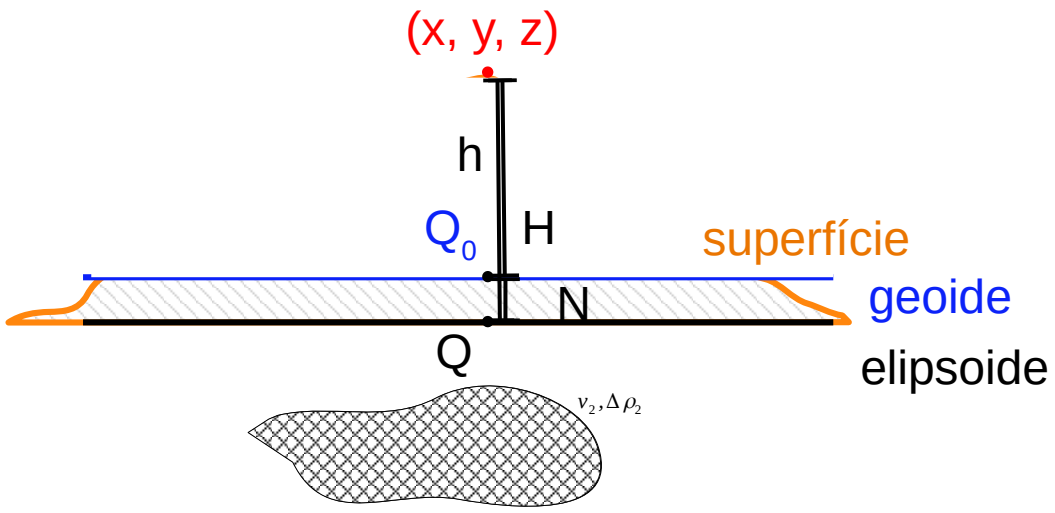
$$\delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h$$

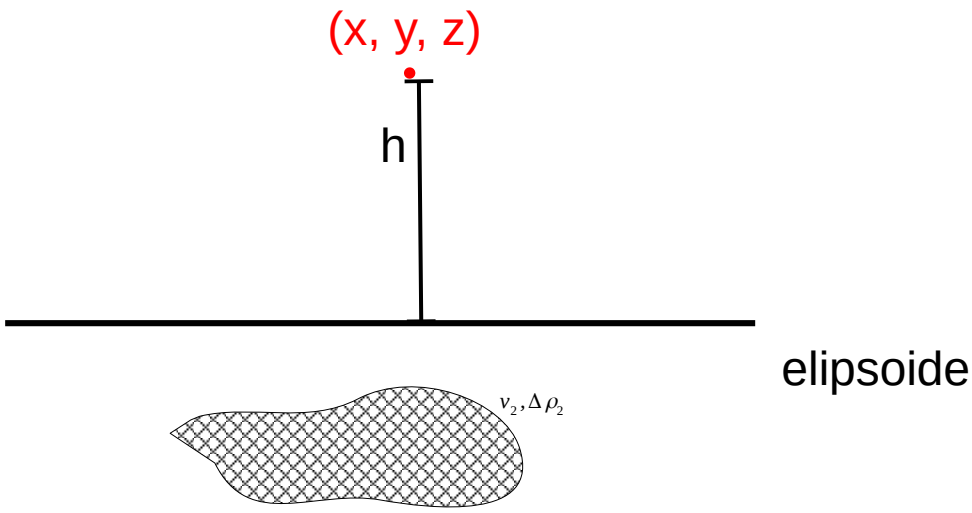




$$\Delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h - 0.3086\, N + 2\pi G\tilde{\rho}_4 N$$

$$\delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h$$

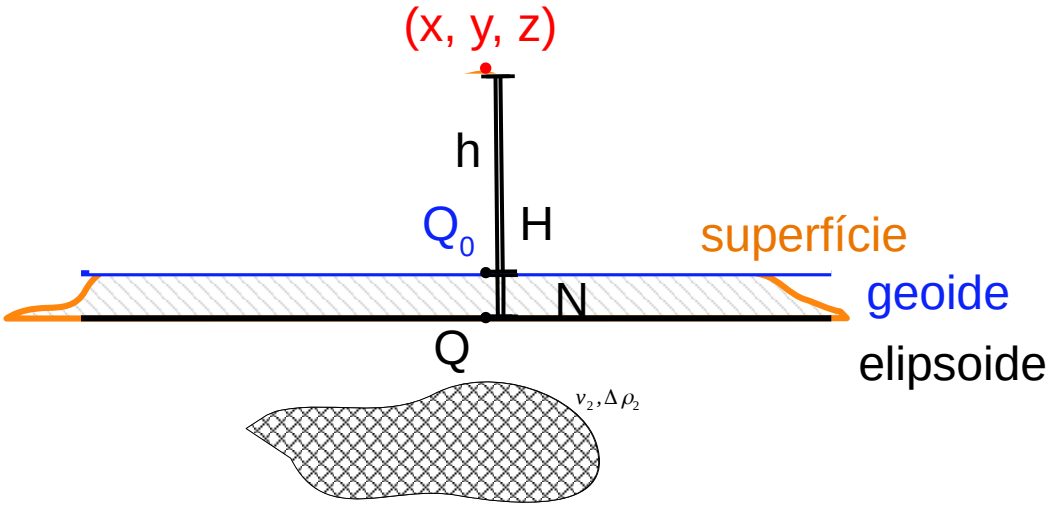


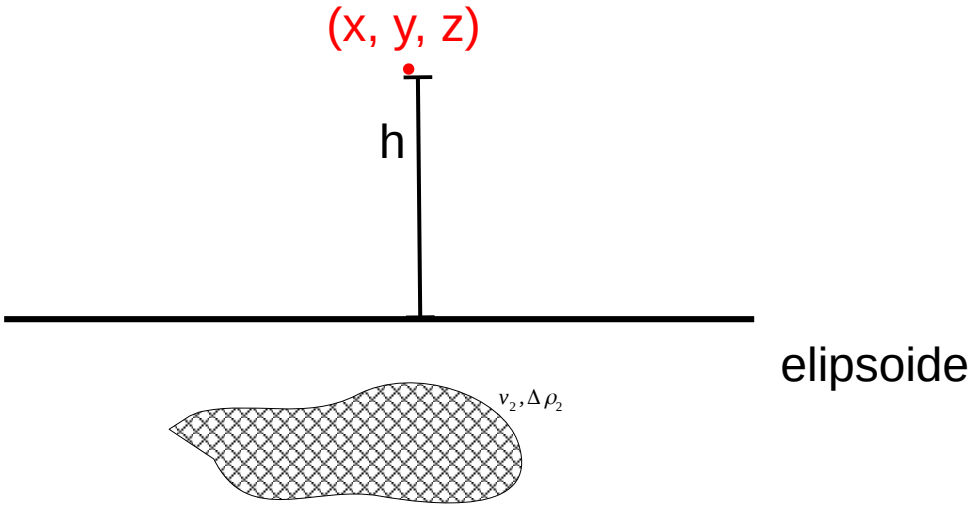


$$\Delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h - 0.3086\, N + 2\pi G\tilde{\rho}_4 N$$

Ar-livre

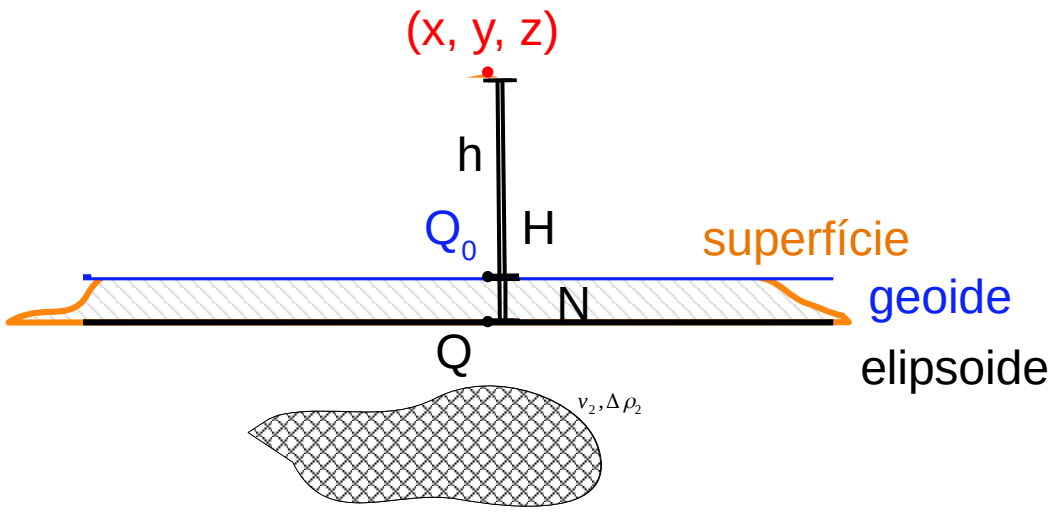
$$\delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h$$



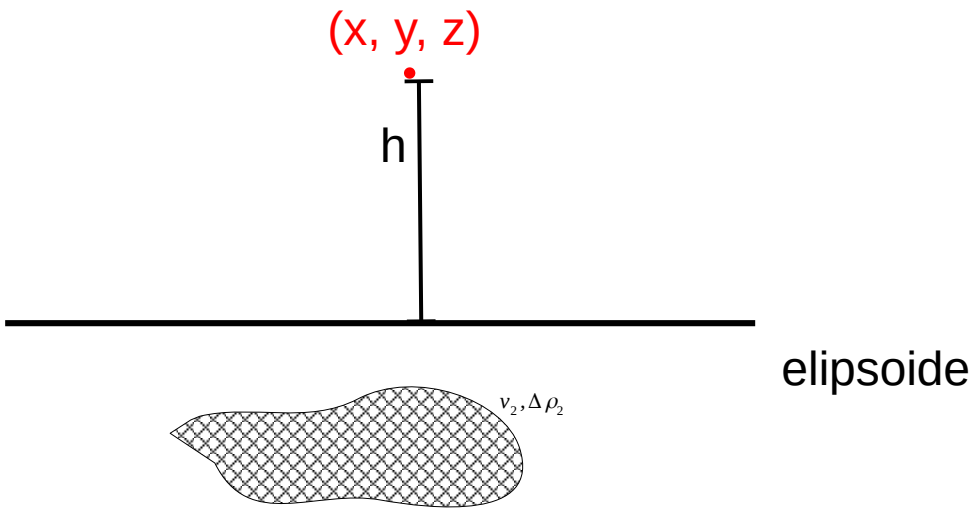


$$\Delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h - 0.3086\, N + 2\pi G\tilde{\rho}_4 N$$

Bouguer



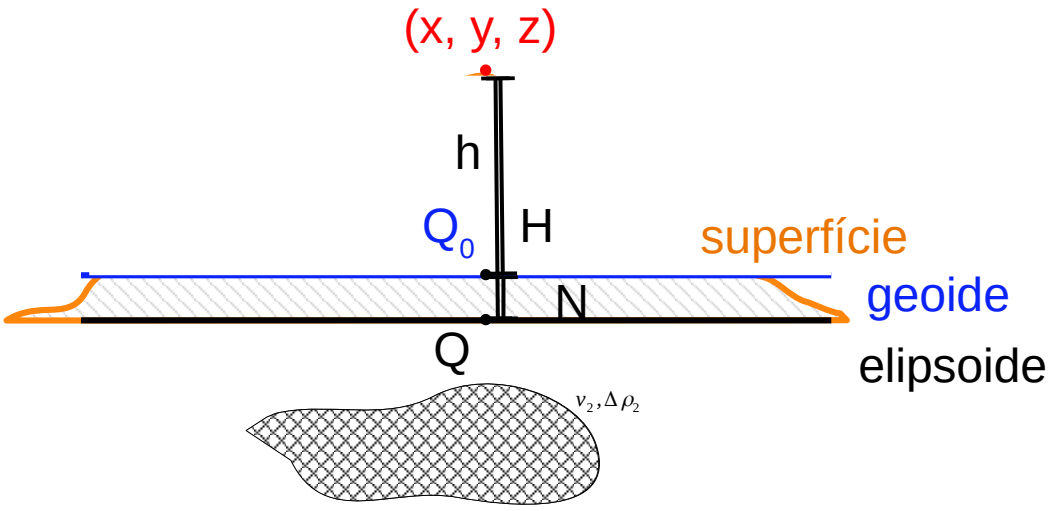
$$\delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h$$

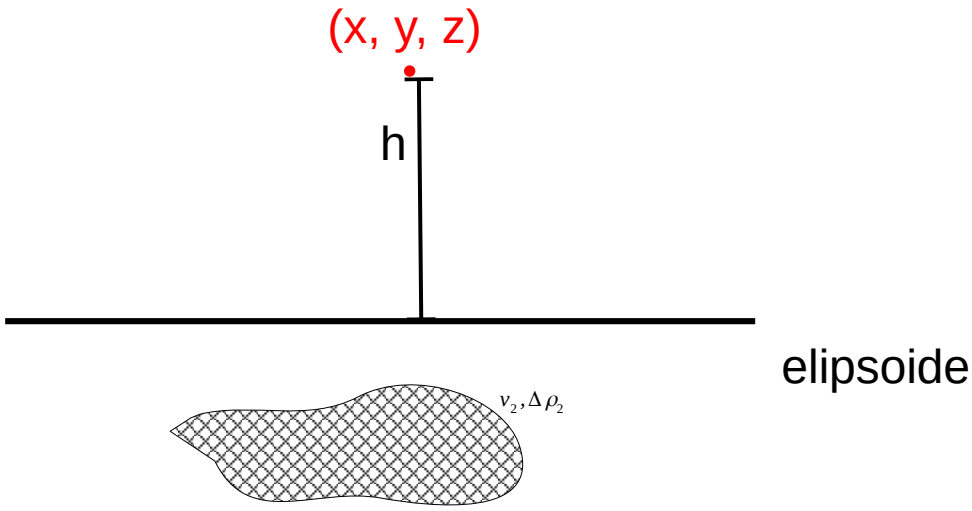


$$\Delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h - 0.3086\, N + 2\pi G\tilde{\rho}_4 N$$

disturbio

$$\delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h$$

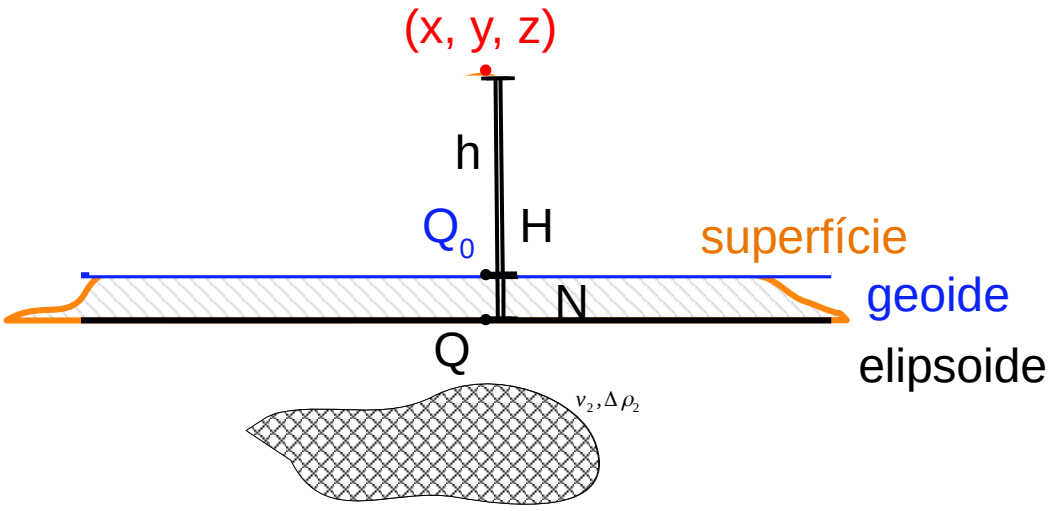


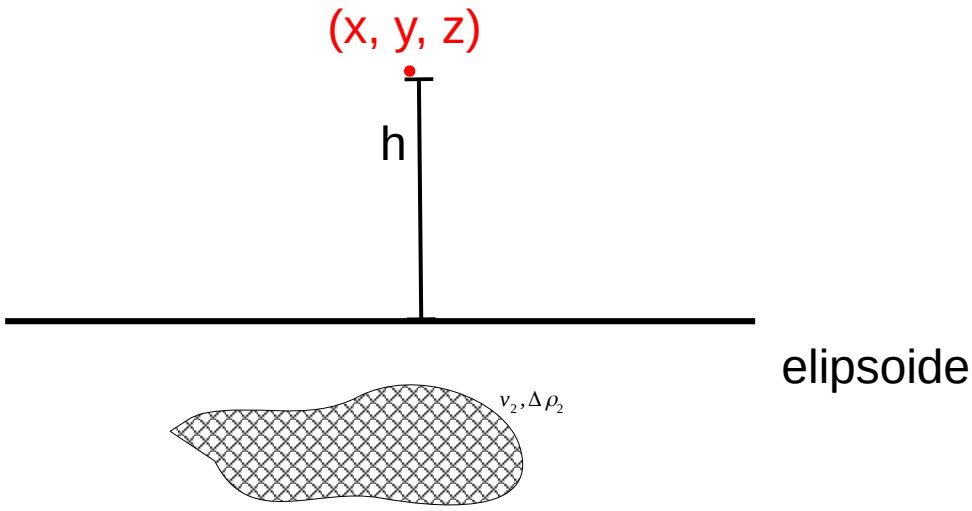


$$\Delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h - 0.3086\,N + 2\pi G\tilde{\rho}_4 N$$

disturbio

$$\delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h$$





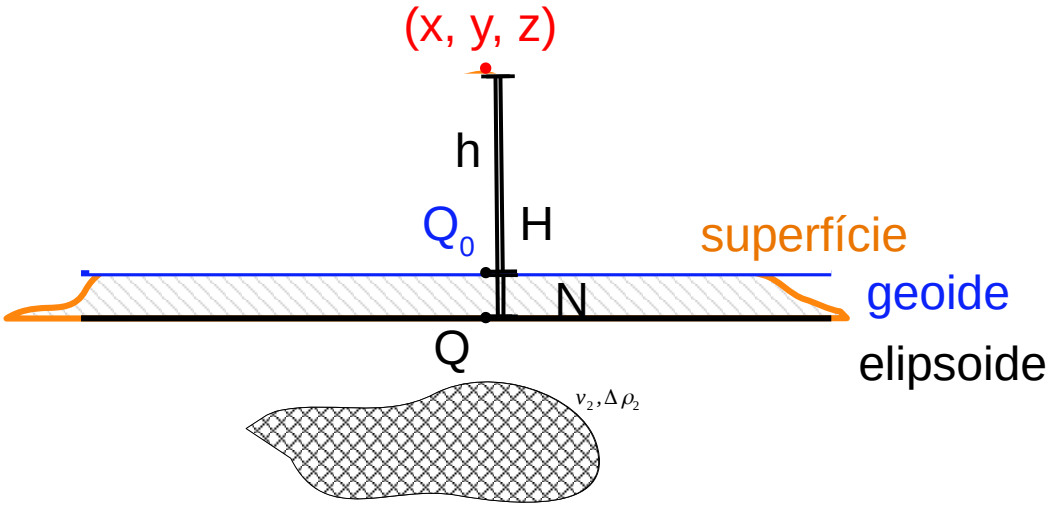
$$\Delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h - 0.3086\,N + 2\pi G\tilde{\rho}_4 N$$

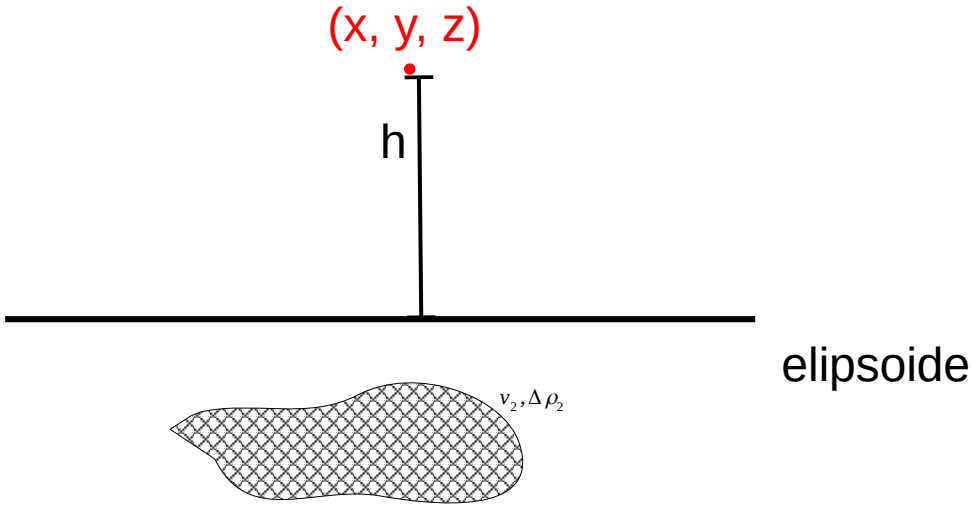
disturbio

Efeito geofísico indireto

(Hinze et al 2005)

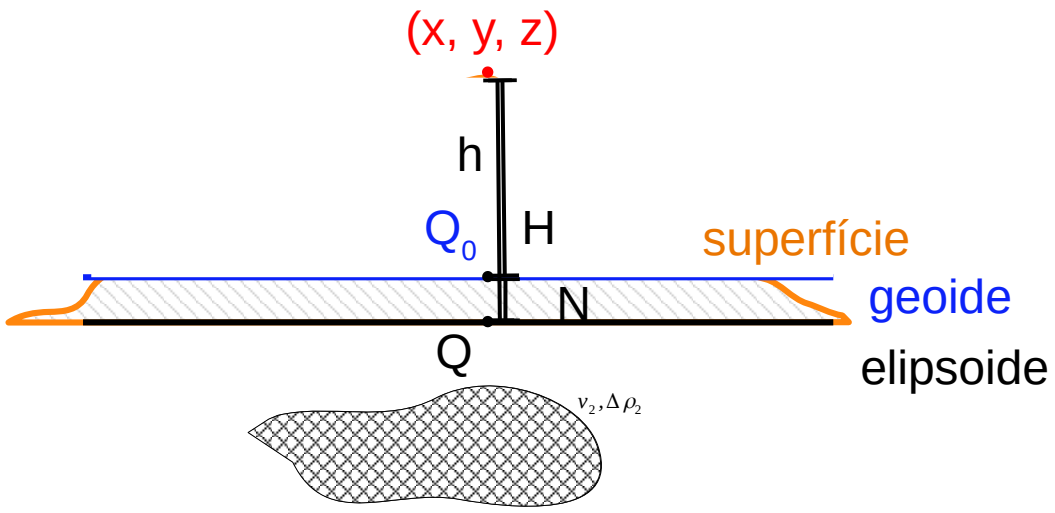
$$\delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 h$$

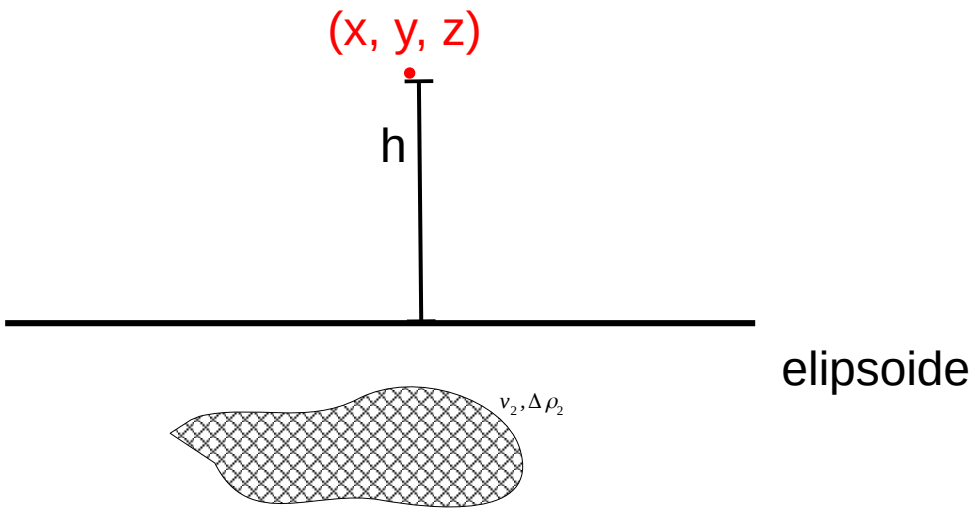




$$\Delta g_P = g_P - \gamma_Q - \left(0.3086\, H + 2\pi G \widetilde{\rho}_4 10^{-5} H\right)$$

$$\delta g_P = g_P - \gamma_P - 2\pi G \widetilde{\rho}_4 10^{-5} h$$



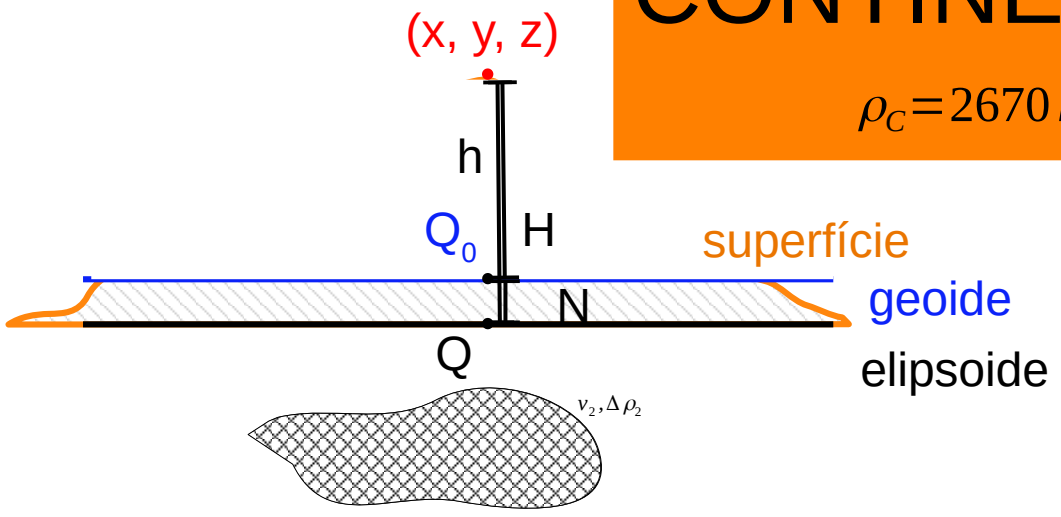


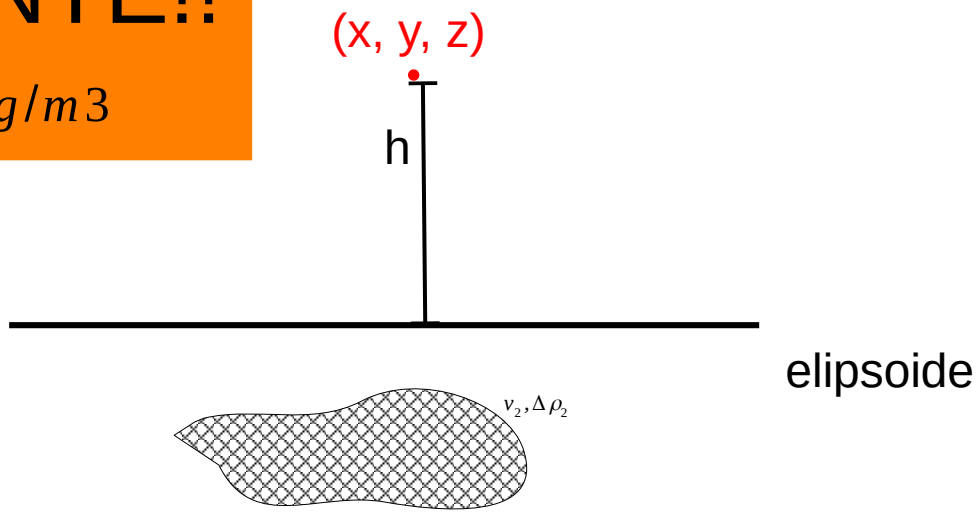
$$\Delta g_P = g_P - \gamma_Q - \left(0.3086\,H + 2\pi G\tilde{\rho}_4 10^{-5} H\right)$$

$$\delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 10^{-5} h$$

CONTINENTE!!

$\rho_C = 2670\,kg/m3$



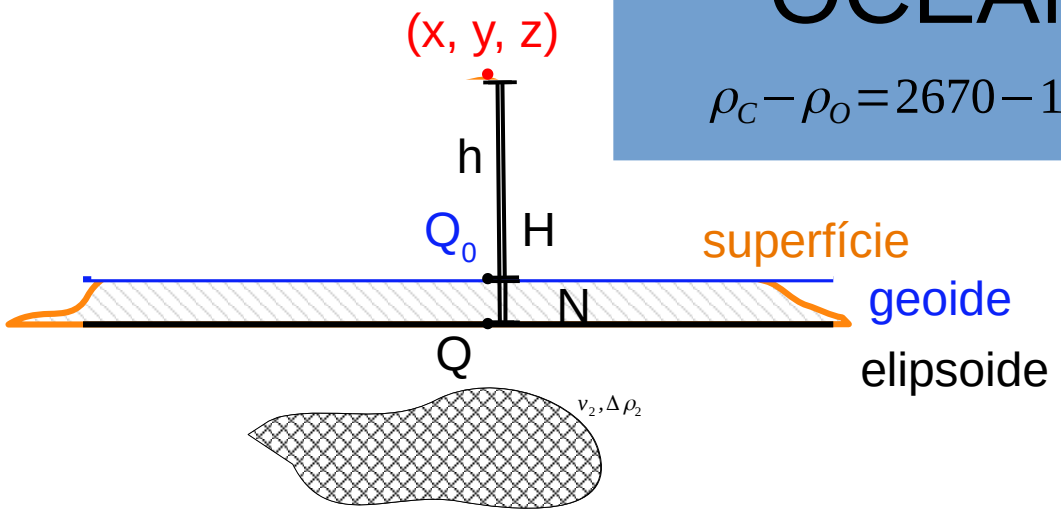


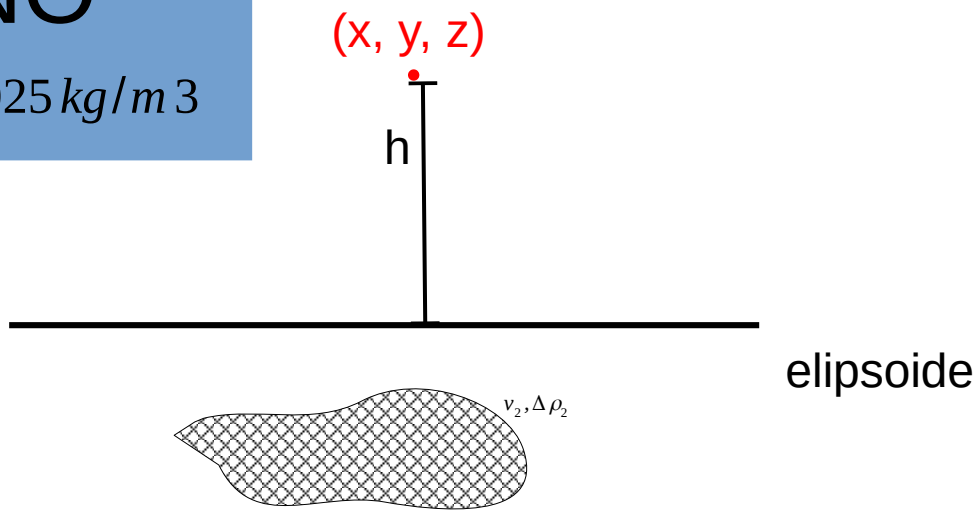
$$\Delta g_P = g_P - \gamma_Q - \left(0.3086\,H + 2\pi G\tilde{\rho}_4 10^{-5} H\right)$$

$$\delta g_P = g_P - \gamma_P - 2\pi G\tilde{\rho}_4 10^{-5} h$$

OCEANO

$$\rho_C - \rho_O = 2670 - 1025\,kg/m3$$





Exercício aula 13

- Calcule as altitudes geométrica, ortométrica e geoidal
  - Altitude geoidal: N = geoide
  - Altitude ortométrica: H = topography
  - Altitude geométrica: h = H+N
- Calcule o gamma_P e gamma_Q usando a função que já está no notebook
- Calcule o disturbio de gravidade usando a formula:

$$\delta g_P = g_P - \gamma_P$$

- Calcule o disturbio corrigido da topografia

$$\delta g_P = g_P - \gamma_P - 2\pi G \widetilde{\rho}_4 10^5 h$$

- Calcule a anomalia ar-livre

$$\Delta g_P = g_P - \gamma_Q - \left(-0.3086\, H\right)$$

- Calcule a anomalia Bouguer

$$\Delta g_P = g_P - \gamma_Q - \left(0.3086\, H + 2\pi G \widetilde{\rho}_4 10^{-5} H\right)$$

Exercício aula 13

- Observações:
- Uso da função Gamma:

```
import gamma
a, f, GM, omega = gamma.WGS84()
gamma_P = gamma.closedform(a, f, GM, omega, latitude, h_surface)
a, f, GM, omega = gamma.WGS84()
gamma_Q = gamma.closedform(a, f, GM, omega, latitude, np.zeros_like(h))
```

- Caso a área contenha continente e oceano, para calcular o disturbio e a anomalia considerando os dois, são necessárias algumas modificações:
  - Calcular o disturbio corrigido da topografia em duas etapas:
    - Calcular o disturbio para os pontos no continente usando o rho_continete = 2067
    - Calcular o disturbio para os pontos no oceano usando (rho_oceano – rho_continente): rho_oceano = 1025
  - Calcular aanomalia bouguer em duas etapas da mesma forma acima

- Variáveis:

```
G = 6.674*1e-11
```

Referencias

- Hinze, W. J., C. Aiken, J. Brozena, B. Coakley, D. Dater, G. Flanagan, R. Forsberg, T. Hildenbrand, G. R. Keller, J. Kellogg, R. Kucks, X. Li, A. Mainville, R. Morin, M. Pilkington, D. Plouff, D. Ravat, D. Roman, J. Urrutia-Fucugauchi, M. Véronneau, M. Webring, and D. Winester, 2005, New standards for reducing gravity data: The north american gravity database: Geophysics, 70, J25–J32. doi: 10.1190/1.1988183