Determination of depth to the magnetic sources using spectral analysis with application to Sicily, Southern Italy

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Presentation outline

- Spectral techniques for depth estimation
- Estimation of depth to the top
- Estimation of depth to the bottom
- Application to magnetic anomalies over the Sicily island, southern Italy
- Concluding remarks

Spectral techniques for depth estimation

- Different spectral techniques may be used for depth estimation assuming either :
  - ✓ a statistical ensemble of blocks (Spector and Grant, 1970; Fedi et al., 1997; Quarta et al., 2000);
  - ✓ a random source distributions (e.g., Blakely, 1988; Tanaka et al., 1999; Trifonova et al., 2009; Chiozzi et al., 2005) or
  - ✓ a fractal source distributions (e.g., Pilkington and Todoeschuck, 1993; Maus and Dimri, 1994; Maus et al., 1997; Bouligand et al., 2009; Bansal et al., 2011; Li et al., 2013; Salem et al., 2014).

- Spectral methods provide valid results if the statistical source model is adequate for the studied region and an optimal window size is chosen for the range of presumed depths

Estimating the depth to the top of magnetic sources

- The slope of the logarithm of the power spectrum of magnetic anomalies, at mid to high wavenumbers, is related to the depth to the top of the source using the following

Models	Equations	Remarks
Statistical ensemble sources	$\ln\langle E(k)\rangle \approx ln(A) - 2k\bar{h} - \beta k$ (where β=2.9)	Suitable for statistical ensembles of homogeneous blocks of different sizes and magnetization
Random and uncorrelated sources	$\ln[E(k)] \approx \ln B - 2kh_t$	Appropriate for a highly variable magnetization distribution
Random and correlated sources	$ln[E(k)] \approx ln\, C - 2kh_t - \beta k$	Appropriate for describing fractal / scaling magnetization distributions

where $E(k)$ is the average power spectrum, *A, B, and C* are constants, $\bar{h}$ is the average depth to the ensemble sources, h_t is depth to the top layer, β is fractal exponent, and k is the wave number

Estimating the depth to the bottom of magnetic sources

- The slope of the logarithm of the power spectrum of magnetic anomalies, at low wavenumbers, is related to the depth to the centroid of the source using the following

	Models	Equations	Remarks
Centroid / modified centroid methods	Statistical ensemble sources	$\ln\langle E(k)\rangle \approx ln(P) - 2k\bar{h}_0 - \beta k$ (where β=0.9)	Appropriate for a statistical ensemble of blocks of different sizes and magnetization
	Random and uncorrelated sources	$ln[(E(k)] \approx ln\,Q - 2kh_o$	Suitable for highly variable magnetization distribution
	Random and correlated sources	$ln[(E(k)] \approx ln\,R - 2kh_o - \beta k$	Appropriate for describing fractal / scaling magnetization distributions

where $E(k)$ is the average power spectrum, P, Q, and R are constants, $\bar{h}_0$ is the average centroid depth to the ensemble sources, h_o is depth to the centroid layer, β is fractal exponent, and k is the wave number

Estimating the depth to the bottom of magnetic sources (cont.)

- The nonlinear fitting is used to simultaneously estimate top depth and thickness of the sources
- The spectral peak is also used in an iterative way to estimate the depth to the bottom
- The de-fractal method requires both the centroid and spectral peak method

Method	Models	Equations	Remarks
Nonlinear inversion	Random and correlated sources	$E[(k) = G - 2kh_t - (\beta - 1)\, ln(k) + \left[-k\Delta h + ln\left(\frac{\sqrt{\pi}}{\Gamma(1+\frac{\beta}{2})}\left(\frac{cosh(k\Delta h)}{2}\Gamma\left(\frac{1+\beta}{2}\right) - K_{\frac{1+\beta}{2}}(k\Delta h)\left(\frac{(k\Delta h)}{2}\right)^{\frac{1+\beta}{2}}\right)\right)\right]$ (Bouligand et al., 2009)	Appropriate for describing fractal/ scaling magnetization
Spectral peak	Random and uncorrelated sources	$k_{peak} = \frac{\ln(h_b) - ln(h_t)}{h_b - h_t}$	Suitable for highly variable magnetization distribution
De-fractal	Random and correlated sources	Requires both the centroid and spectral peak method	Appropriate for describing fractal/ scaling magnetization distributions

where $E(k)$ is the averaged power spectrum, G is a constant, h_t is depth to the top layer, h_b is depth to the bottom, Δh is the thickness, Γ is gamma function, K is modified bessel function of the second kind, β is fractal exponent, and k is the wave number

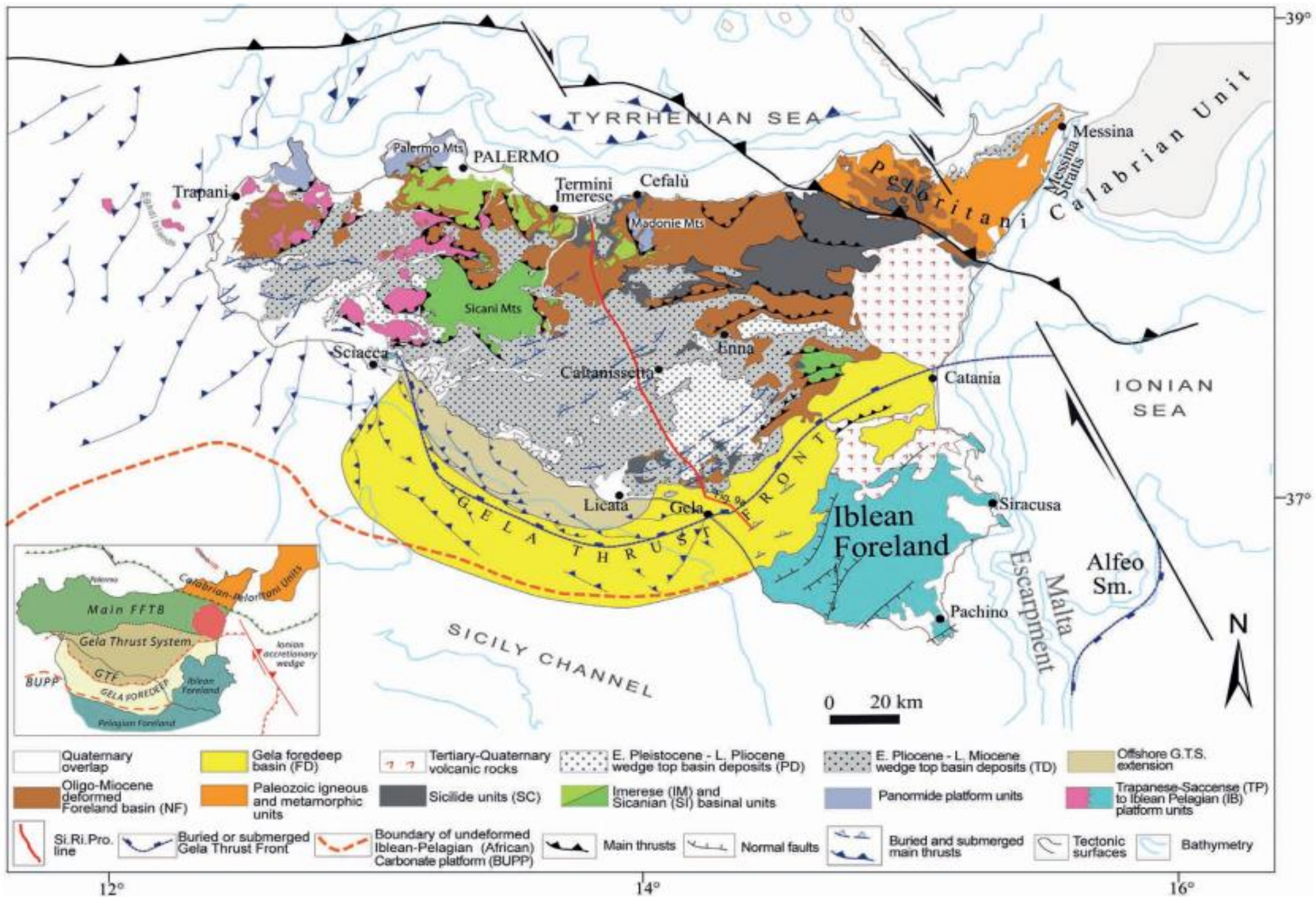
- Spectral techniques for depth estimation: Theoretical models

Test of the methods on theoretical data: Synthetic examples

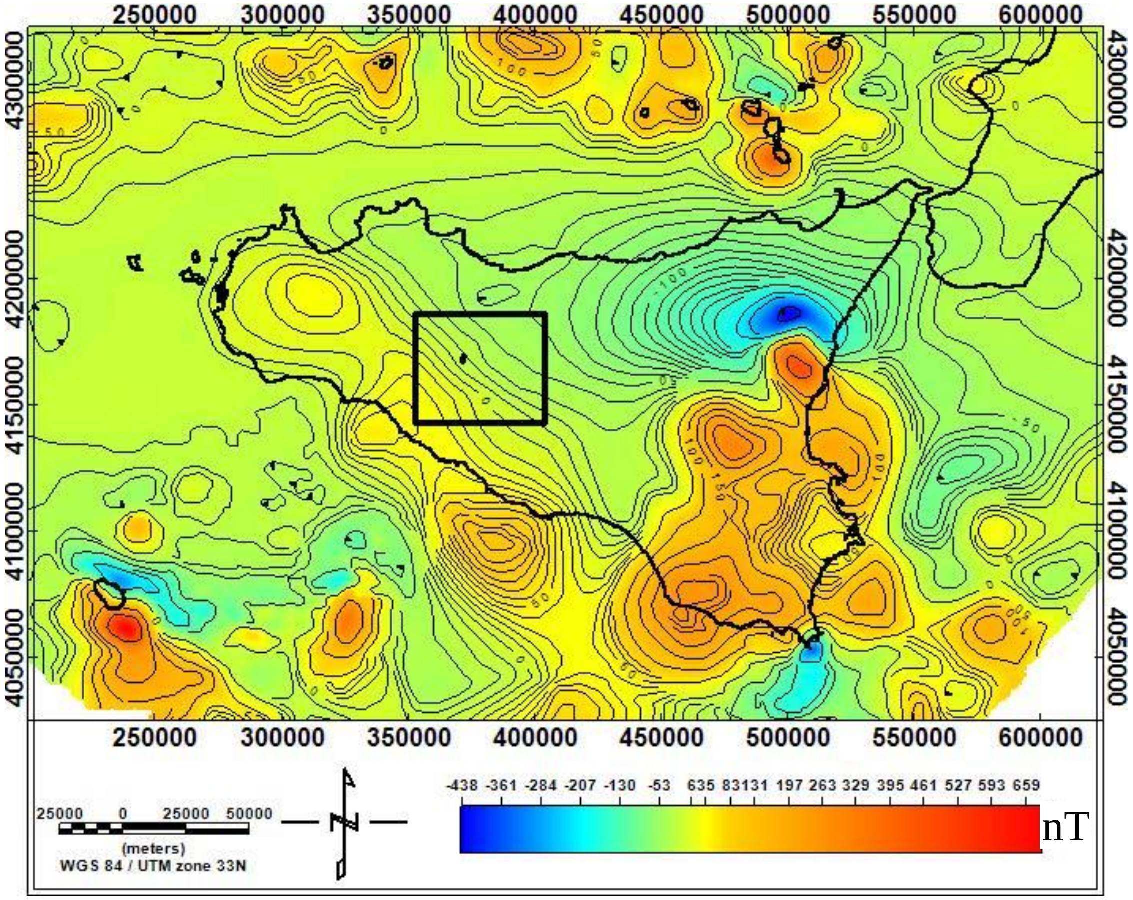
Application to magnetic anomalies over the Sicily island, southern Italy

- Summary and conclusions

Determination of depth to the magnetic sources : the case of Sicily, Southern Italy



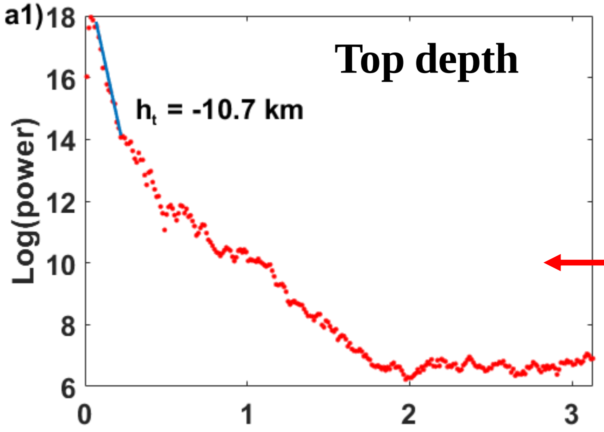
Geological map of Sicily (after Catalano et al., 2013)

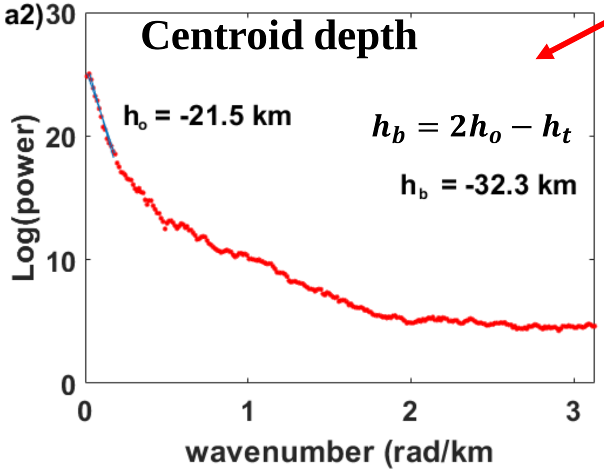


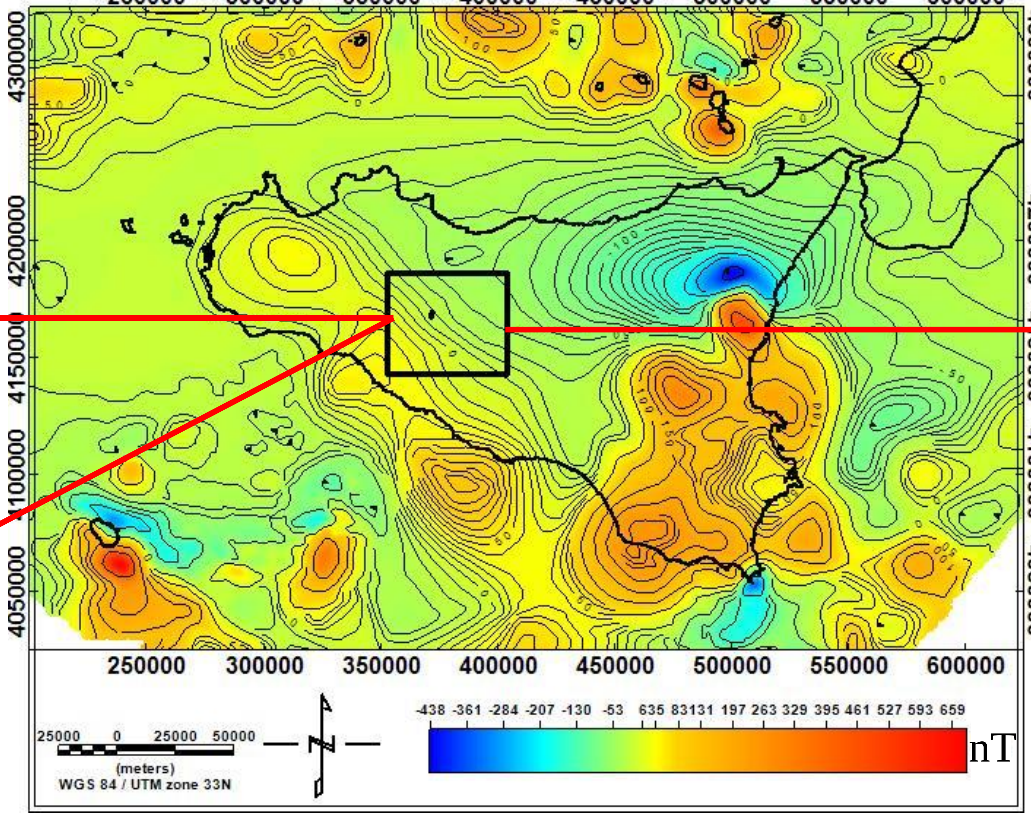
Aeromagnetic anomaly map of Sicily and surrounding environs (data from Agip, 1981)

Determination of depth to the magnetic sources : the case of Sicily, Southern Italy

Centroid method: assuming statistical ensemble

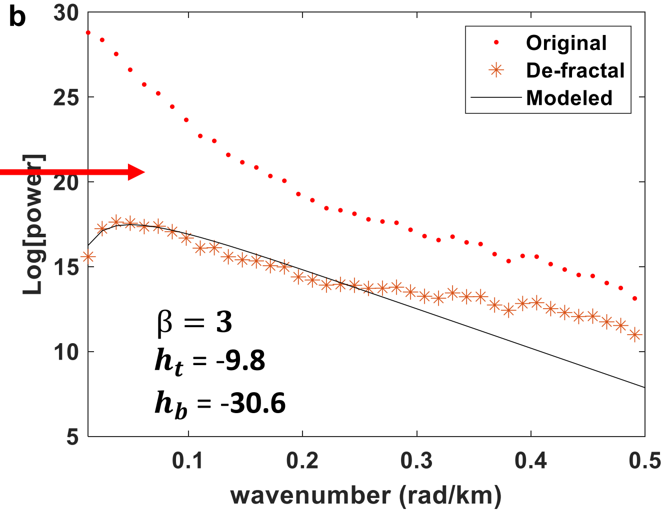






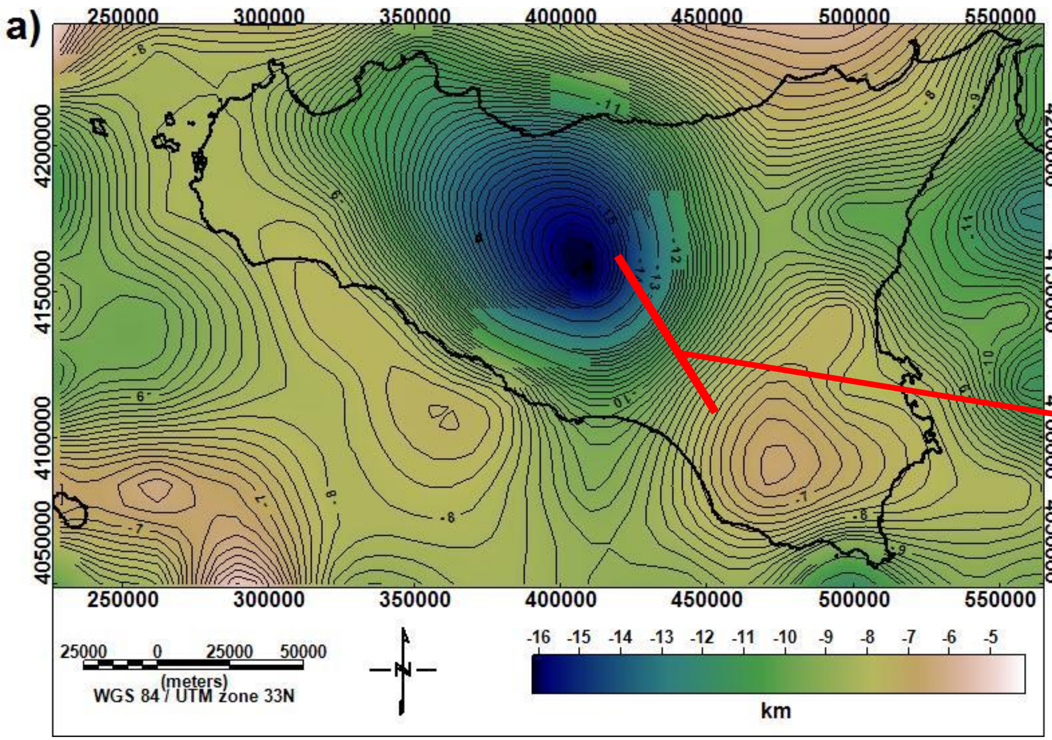
Aeromagnetic anomaly map of Sicily and surrounding environs

De-fractal method

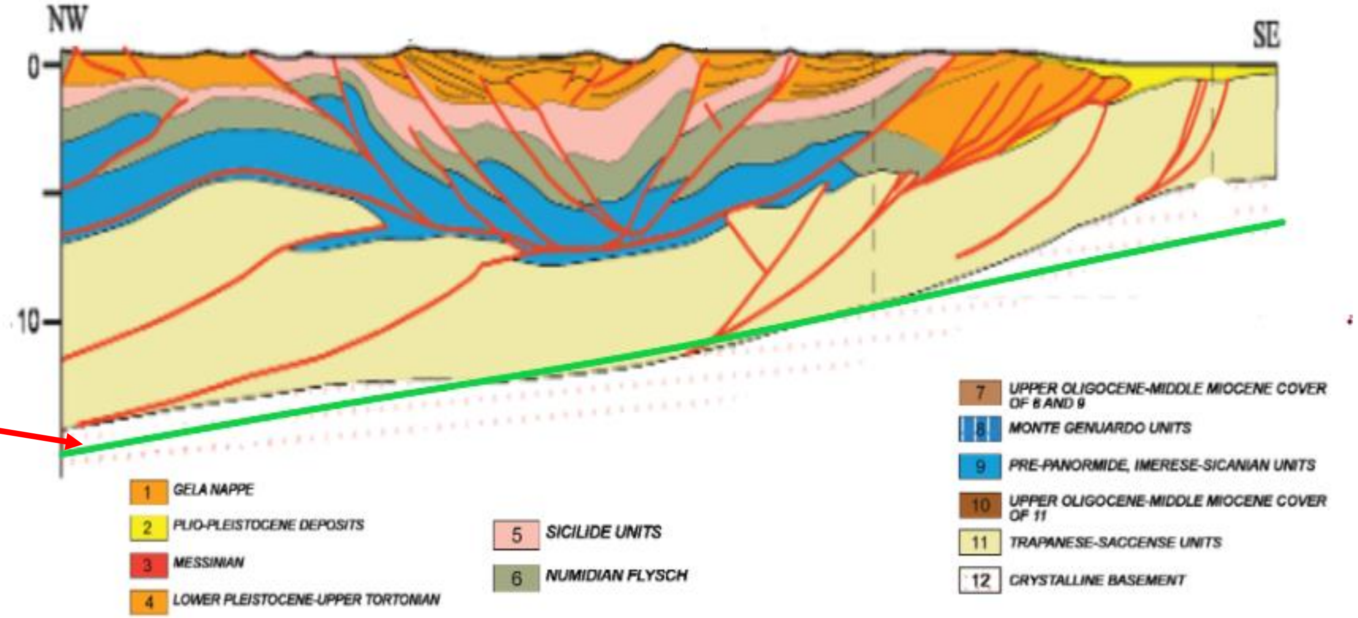


Determination of depth to the magnetic sources : the case of Sicily, Southern Italy

Depth to the top of crystalline basement

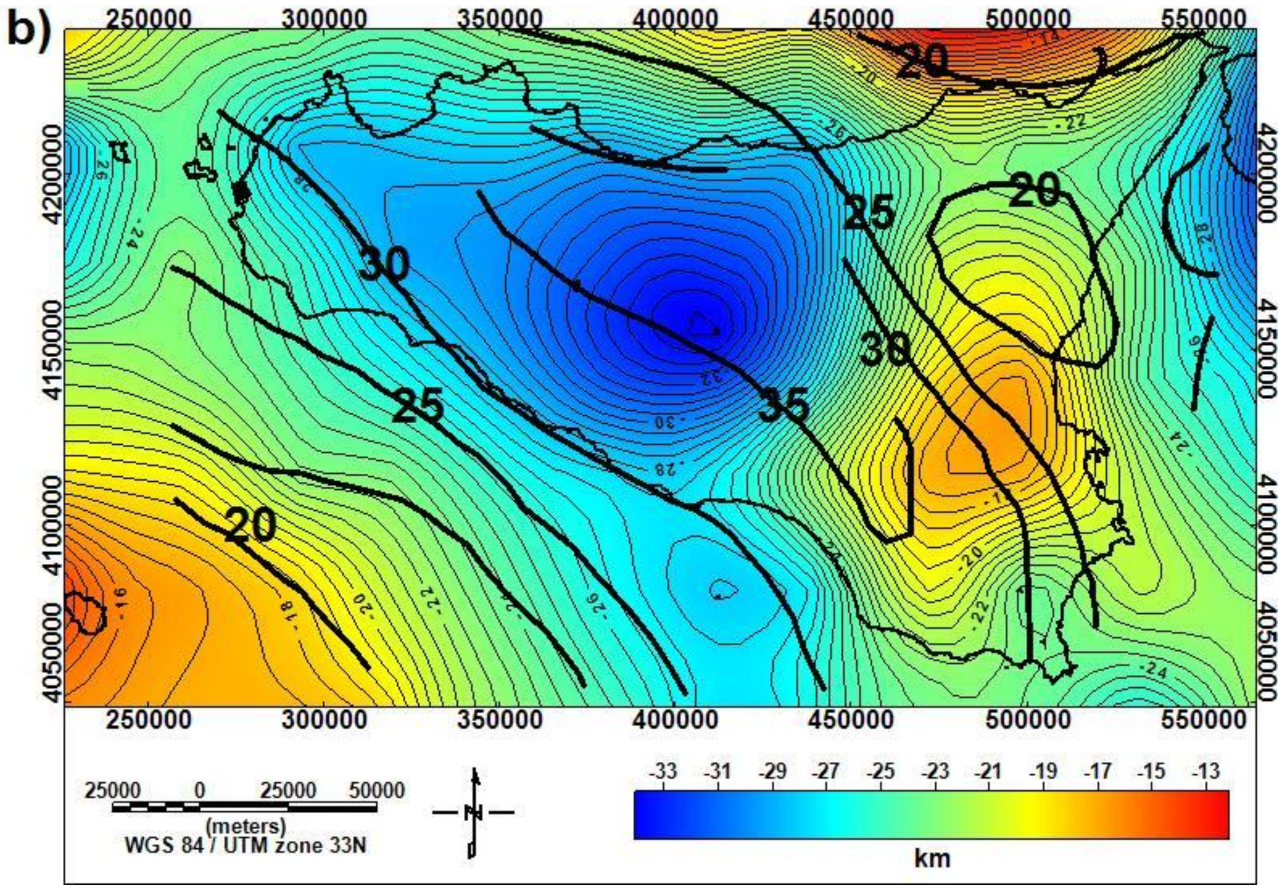


Balanced cross section (after Catalano et al., 2002)

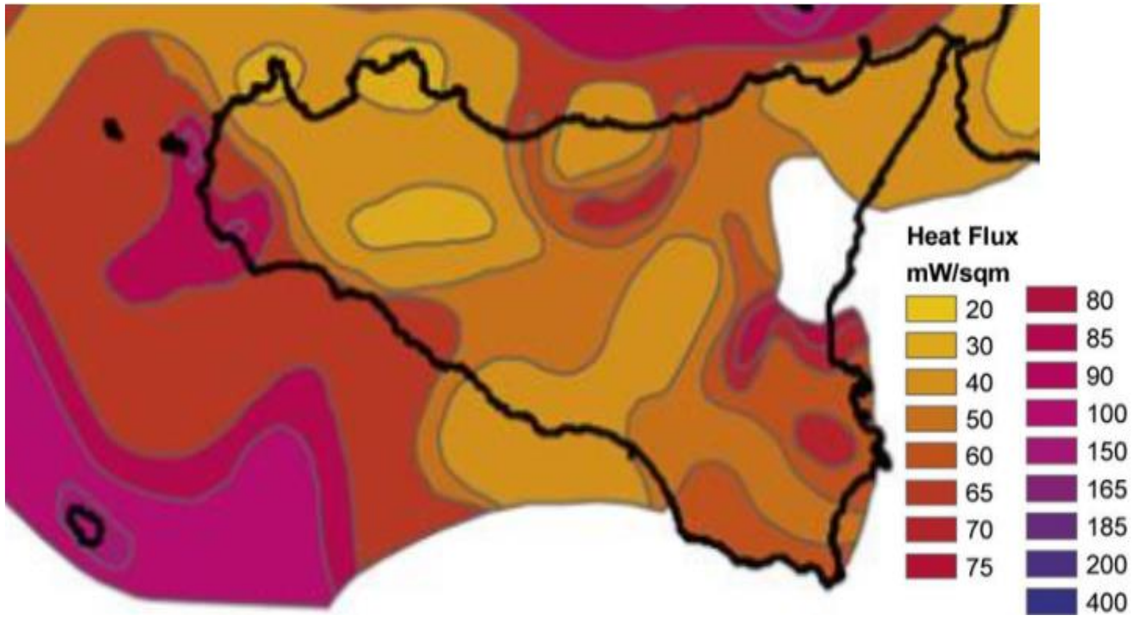


Determination of depth to the magnetic sources : the case of Sicily, Southern Italy

Depth to the bottom / Curie isotherm



Heat flow map (Boschi et al., 2011)



Thick black lines indicate Moho depths (after Giustiniani et al., 2018)

Concluding remarks

- Critical evaluation of the different spectral techniques for depth estimates for different source models may lead to a robust and geologically meaningful outcomes.
- Depth estimation using spectral methods requires a critical evaluation of window size, window location, and wavenumber range.
- Despite of the plenty of existing spectral methods, statistical ensembles with depth correction is extremely valid for fields from relatively blocky distribution of magnetization.
- Magnetic basement depth values are estimated to be 5–10 km beneath the Iblean Plateau, 7–10 km in western Sicily, and 16 km in the central Sicily (Caltanissetta basin).
- Curie depth values are estimated to be 16–20 km beneath the Iblean Plateau, 26–30 km in western Sicily, and about 35 km in the central Sicily
- Despite local discrepancies, the Curie depth values agree with heat flow and Seismic Moho depth and show the expected model

Acknowledgements

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