Characterization of the Eastern Galicia Magnetic Anomaly (EGMA). A warning regarding the interpretation of aeromagnetic data

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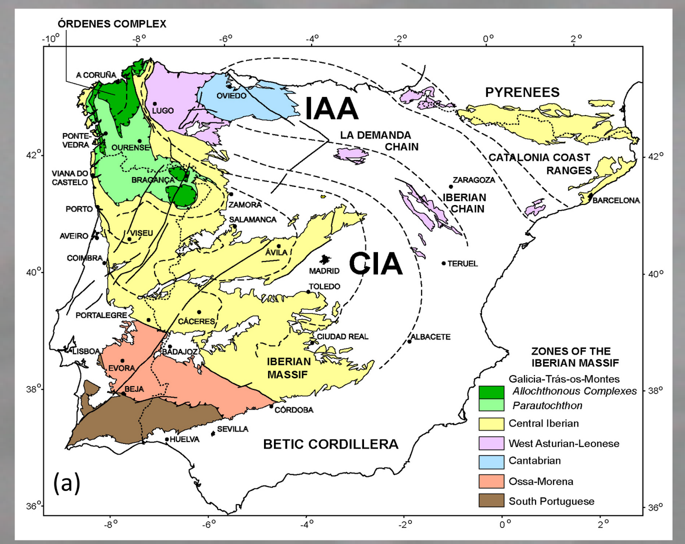
SUMMARY: Regional aeromagnetic data are an excellent diagnostic tool to unravel geological problems. However, these datasets are often interpreted by modeling non-outcropping rocks of unknown magnetic properties. Accordingly, resulting models are largely unreliable. One of such examples is the EGMA, located in NW Spain and overlying the Late Variscan Lugo-Sanabria extensional dome (Figure 1b). Reaching 190 nT, it has been traditionally interpreted by buried bodies with a magnetic susceptibility that is, obviously, a trade-off between the size/depth of the magnetic source and the value of the anomaly. Remanent magnetization was never taken into account and the role of structures was overlooked. Recent detailed surveying in the Xistral Tectonic Window, at the northern part of the EGMA, showed that migmatites, inhomogeneous granites and Late Proterozoic and Early Cambrian metasediments might be highly magnetic in some areas (Figure 2), reaching susceptibilities of κ=0.2 (SI), although values of κ=0.02 are more common. Optical, rockmag and XRD studies suggest that the main magnetic mineral is MD magnetite (Figures 2f and 6a). However, thermal demagnetization shows that hematite is carrying a magnetic remanence, often with low inclination, reverse polarity, and striking ~N160º (Figure 5), consistent with a Permo-Triasic chron. AMS studies (Figure 8) show very high anisotropies linked to magnetite (Figure 7), with directions that mimic those of late Variscan extensional shear zones (E1 and E2). Finally, high isotopic ratios ($\delta^{18}O$) from magnetic granites and migmatites suggest that the latter are the melting products of metasediments. These data indicate that the source of the anomaly is linked to metasediments and their melting products but only when affected by extensional detachments. Low pressure inherent to extensional tectonics and associated high temperatures seem to be key in the crystallization of magnetite in these structures. This fact explains the high AMS values and the heterogeneity of the magnetic rocks. Finally, the existence of remanent magnetization must be taken into account in the interpretations since high Königsberger ratios exist (average Qn=0.875). These findings alone imply the need of including a number of significant changes in the EGMA existing models.

1. THE CENTRAL IBERIAN ARC (CIA) AND THE EASTERN GALICIA MAGNETIC ANOMALY (EGMA)



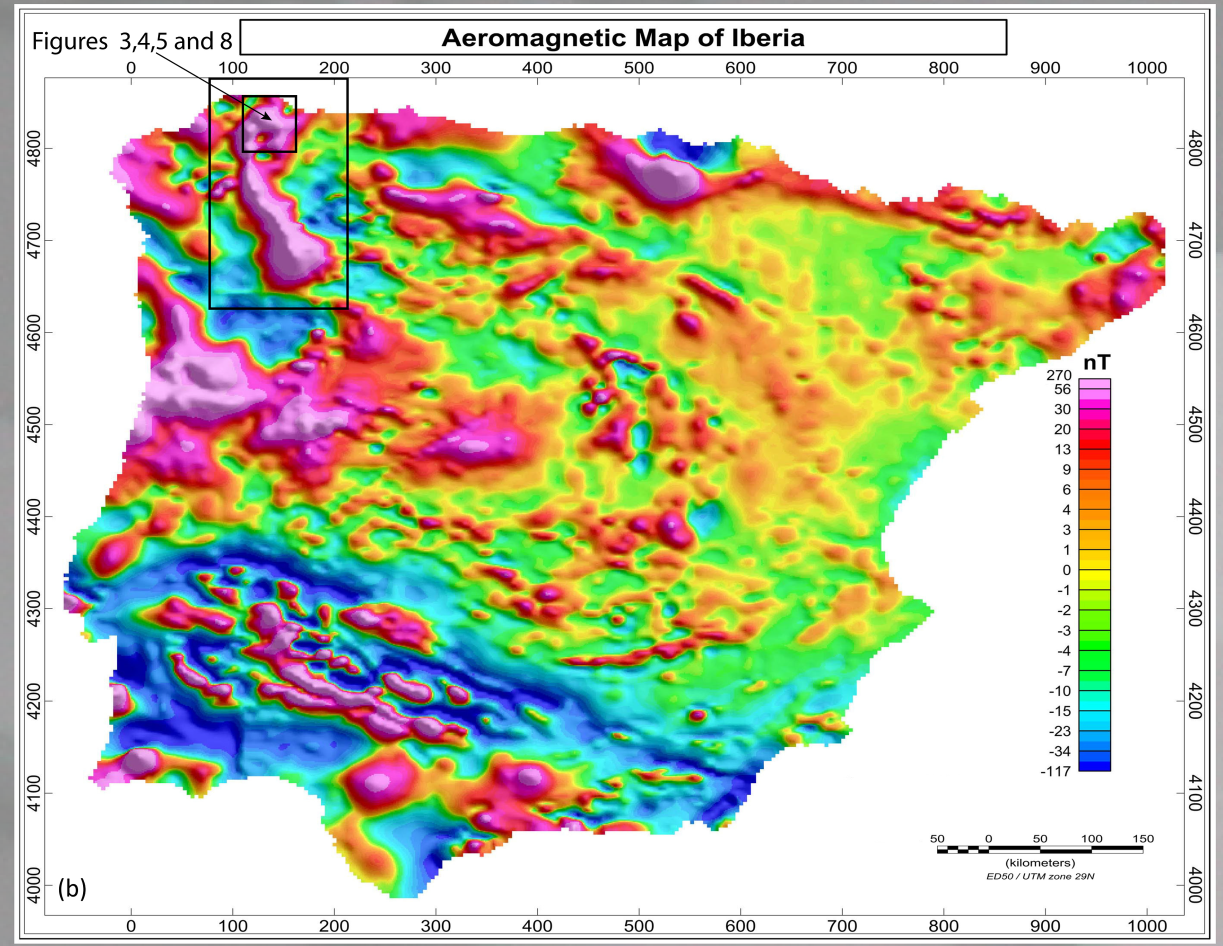


Figure 1: a) Geological map of the Iberian Massif with its six different tectonic zones. IAA: Ibero-Armorican Arc. CIA: Central Iberian Arc. Dashed lines indicate the direction of the main structures (from Martínez-Catalán et al., 2012). b) Aeromagnetic map of Iberia (data from Ardizone et al. (1989) for Spain and Miranda et al. (1989) for Portugal). Observe the magnetic anomaly associated to the Central Iberian Arc. The rectangular area comprises the EGMA and the square area, the anomaly in the Xistral tectonic window, to the N of the Lugo-Sanabria dome, where the magnetite bearing rocks that source the anomaly outcrop. This is the area of the land surveying shown in Figures 3 and 4, where the samples for analysis had been picked

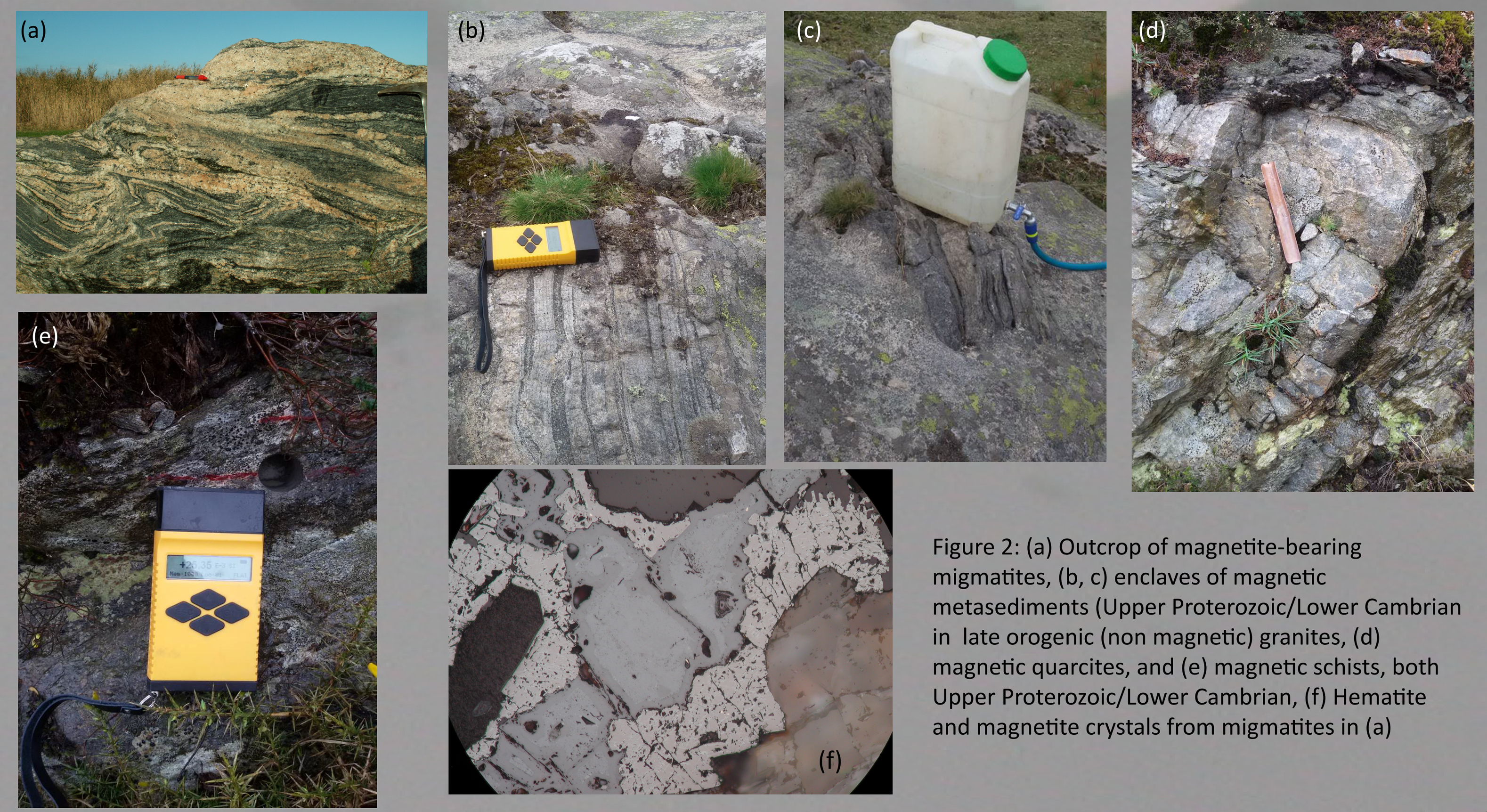


Figure 2: (a) Outcrop of magnetite-bearing migmatites, (b, c) enclaves of magnetic metasediments (Upper Proterozoic/Lower Cambrian in late orogenic (non magnetic) granites, (d) magnetic quarcites, and (e) magnetic schists, both Upper Proterozoic/Lower Cambrian, (f) Hematite and magnetite crystals from migmatites in (a)

2. THE XISTRAL TECTONIC WINDOW

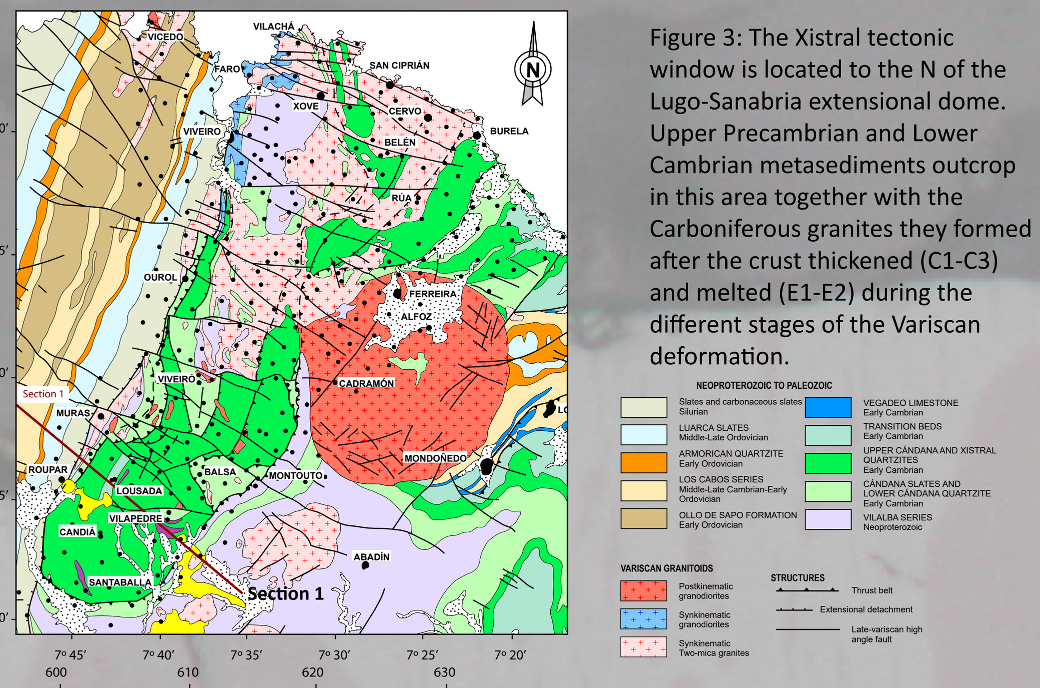


Figure 3: The Xistral tectonic window is located to the N of the Lugo-Sanabria extensional dome. Upper Precambrian and Lower Cambrian metasediments outcrop in this area together with the Carboniferous granites they formed after the crust thickened (C1-C3) and melted (E1-E2) during the different stages of the Variscan deformation.

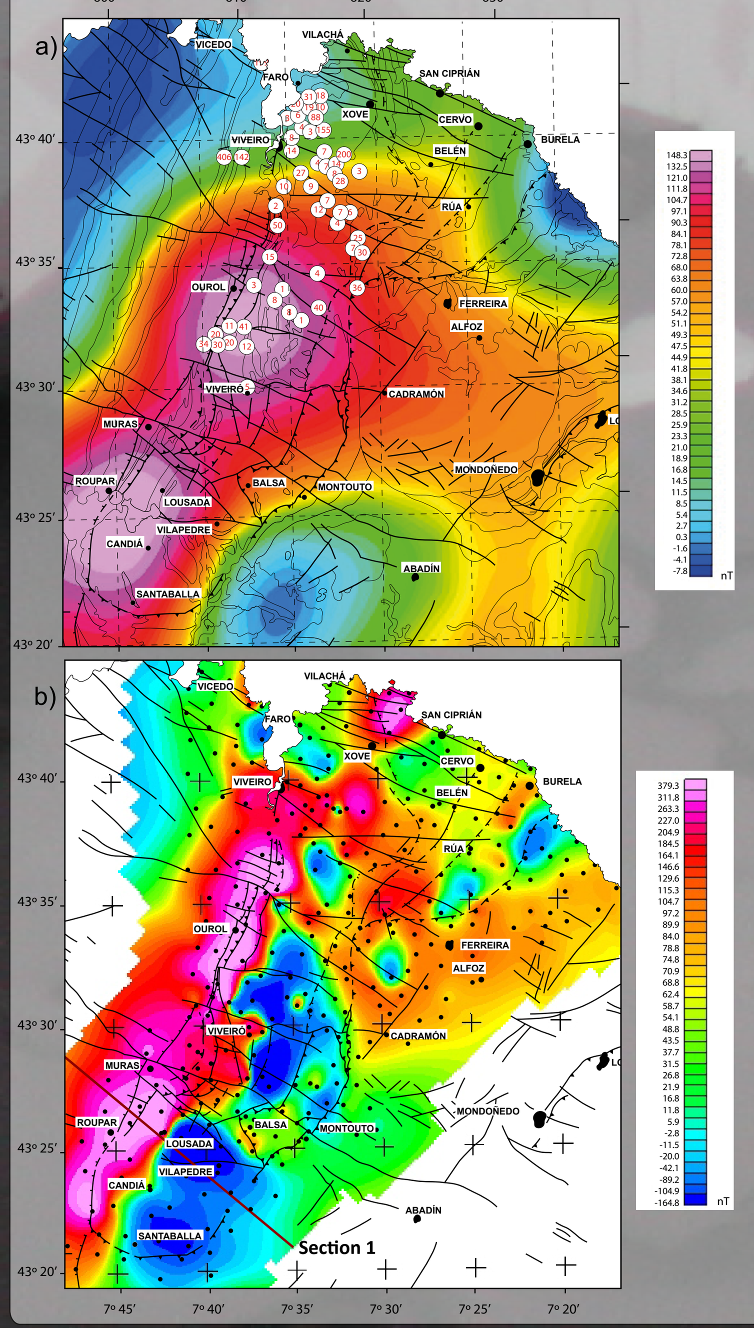


Figure 4: (a) Aeromagnetic anomaly of the Xistral Tectonic Window as seen in Figure 1b. Circles include de values of outcropping rocks magnetic susceptibility (S.I.x10³units). (b) Reduced to the pole magnetic anomaly over the same area as (a) after land surveying. Observe how maxima coincide with the Viveiro normal fault and extensional detachment. Other maxima appear on top of extensional detachments too. Points represent the acquisition locations. Compare the resolution of this map, acquired on land, with that in (a), extracted from the aeromagnetic data of the Iberian Peninsula (Figure 1b).

3. NRM and ROCK MAGNETIC ANALYSIS

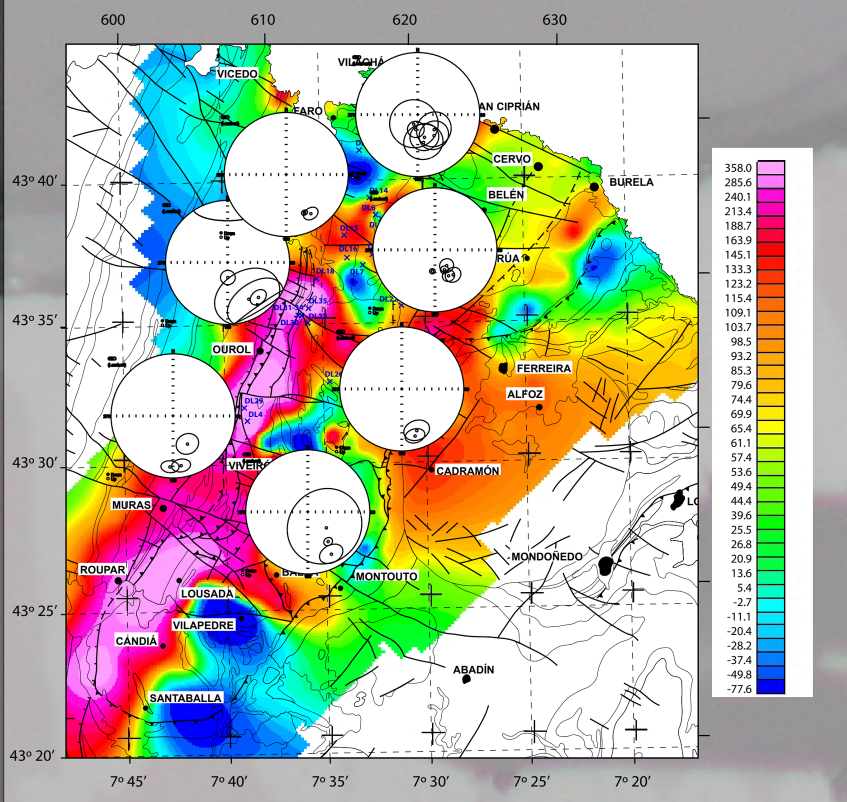


Figure 5: Analysis of the NRM shows a very consistant remanence of SW direction, reverse polarity, and variable inclination. When inclination is low, NRM results might represent the Lower Carboniferous-Upper Permian superchron (Kiaman Superchron), which coincides with the age fo the youngest melting episodes. Higher inclinations might represent post-magnetization folding/ tilting or a younger remagnetization. Königsberger ratios reach Qn> 1000, the average being Qn=0.875. Thus NRM results should be included in the EGMA models.

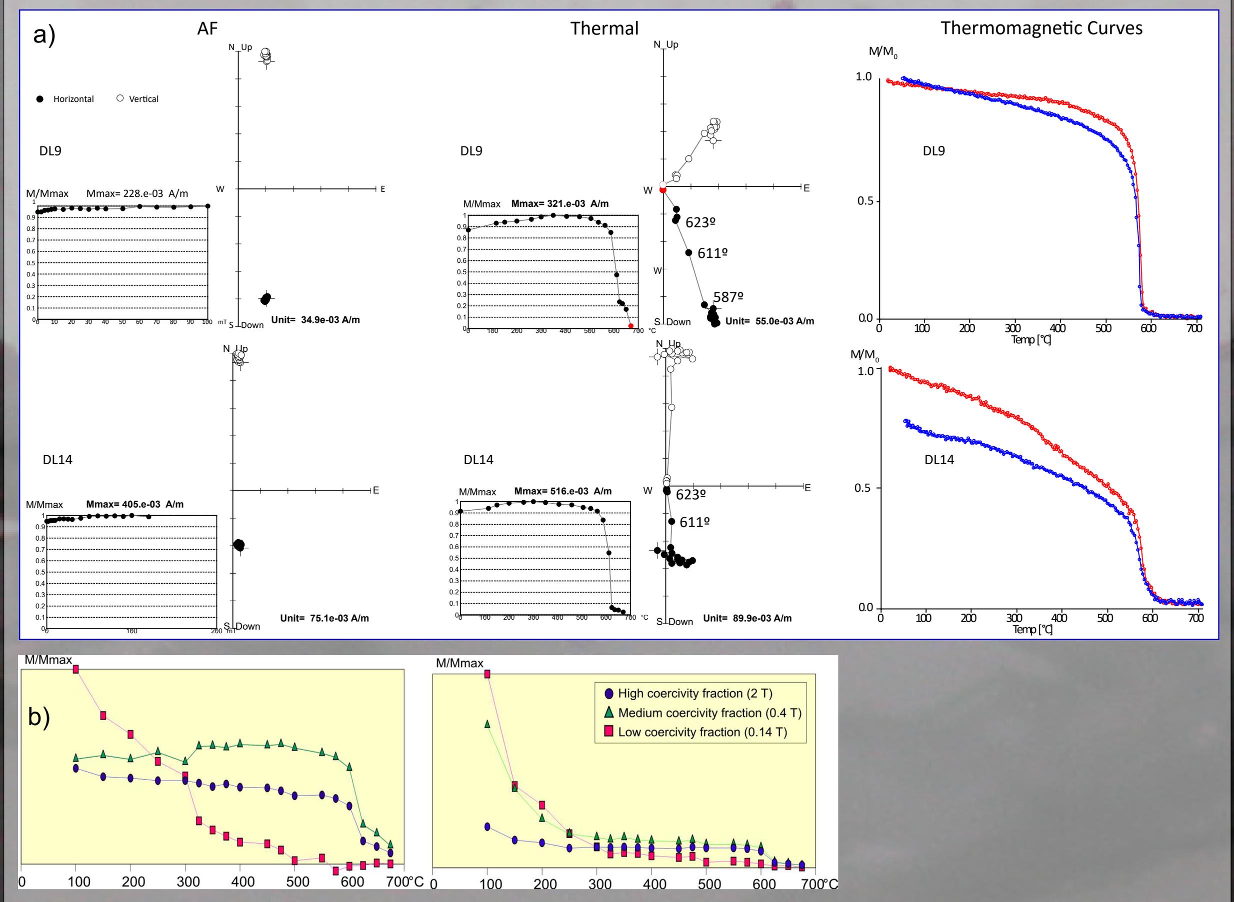
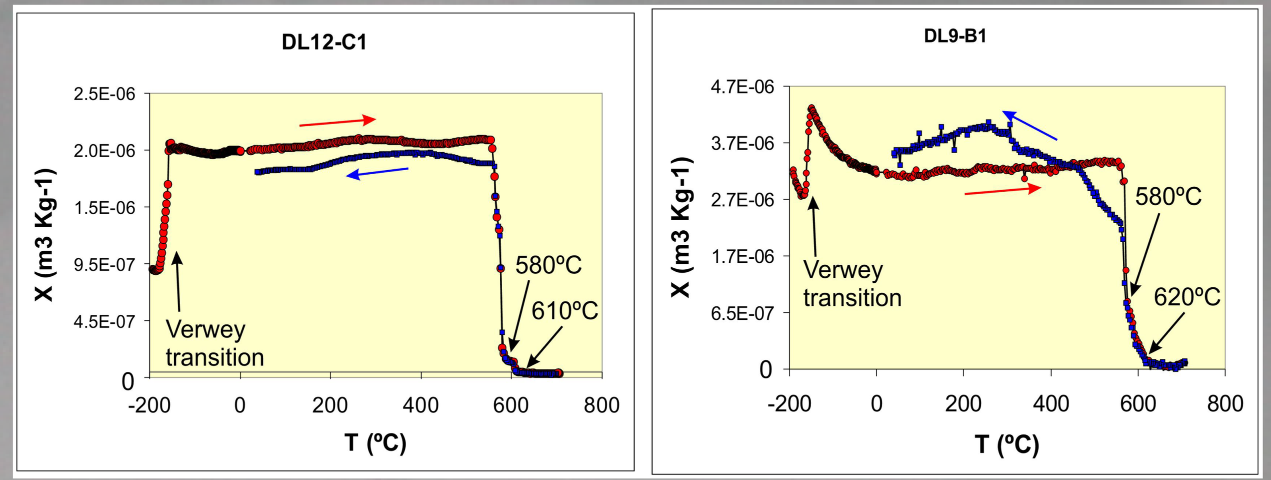


Figure 6: (a) Orthogonal plots of NRM alternating field (AF) and thermal demagnetization and thermomagnetic curves of two examples of the most common type of magnetic behaviour. NRM demagnetization shows that it is high coercitivity phases with Tc >623ºC that carry remanence (i.e. low content Ti-hematite). However, thermomagnetic curves and other rockmag experiments indicate that induced magnetization is controlled by MD magnetite. Rockmag experiments enhance low coercivity minerals that not contribute to the NRM
(b) Two examples of thermal demagnetisation of a composite three axis IRM (orthogonally induced at 2, 0.4 and 0.12 T, respectively as described by Lowrie (1990). Both examples confirm the presence of high coercivity phases with unblocking temperatures of 625°C probably due to low-Ti titanohematite, as well as hematite.

Figure 7: Examples of susceptibility thermomagnetic curves exhibiting very clear Verwey transitions and sharp Curie drops at 580°C, evidencing the dominance of magnetite in the susceptibility and thus in the AMS. Magnetite is MD and the high degree of anisotropy (P, Figure 8) is probably due to big elongated MD magnetite grains. In addition, drops in susceptibility can be also observed at 620°C, probably due to low-Ti content titanohematite. Magnetic minerals carrying the NRM do not play a role in the ASM.



4. ANISTROPY OF THE MAGNETIC SUSCEPTIBILITY (AMS)

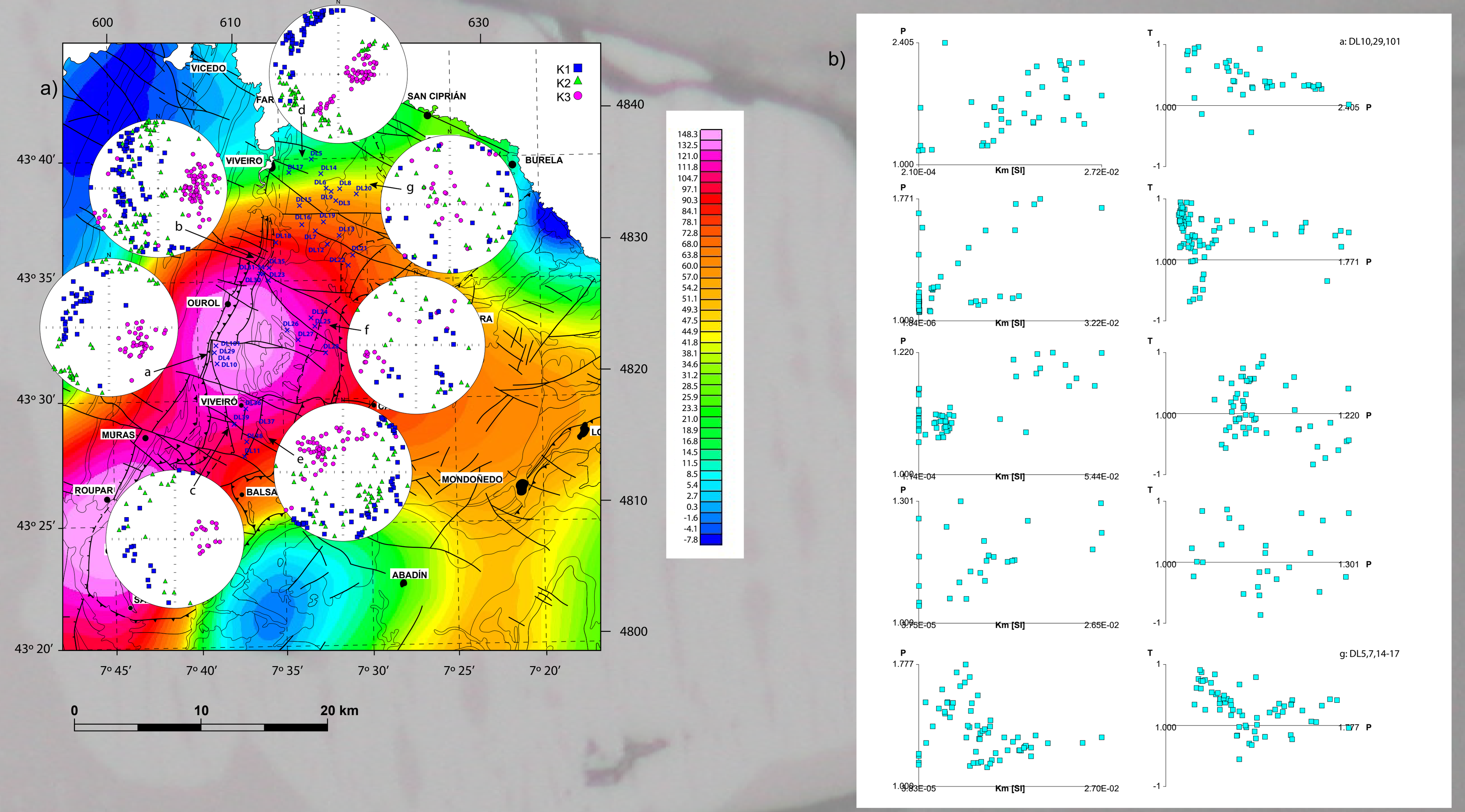


Figure 8: (a) Lower hemisphere equal area projection of the main axes of the AMS ellipsoid for two structurally coherent sites. k1 (maximum), k2 (intermediate) and k3 (minimum). To the W, a, b c and d show AMS planes with directions and dips that match those of the Viveiro Normal Fault and its extensional (E2) detachemnt (~N-S/45ºW). To the E, e,f, and g indicate anisotropy planes with NW directions and easterly dips that mimic the setting of E1 extensional detachments, which where later affected by the compresional C3 phase.
b) Total anisotropy (P) vs magnetic susceptibility (k) and T parameter as a funciont of P values. The degree of anisotropy is very high (P=2.4) in some samples. Clear direct relationship between P and κ suggest that magnetite is the main anisotropic magnetic mineral. The sceptibility ellipsoide is oblate most of the times.

CONCLUSIONS

The source of the EGMA, one of the magnetic anomalies characterizing the Central Iberian Arc, is magnetite and low Ti-hematite bearing granites and migmatites of Carboniferous age and upper Proterozoic-Lower Cambrian metasediments. In fact, geochemical analysis ($\delta^{18}O$) show that granites and migmatites are the melting product of those metasediments. These magnetic rocks only outcrop in the Xistral tectonic window. The high magnetic susceptibilities found in the area are represented by MD magnetite, but newly identified NRM of inverse polarity and SSW directions is carried, mostly, by low Ti-hematite. Recently studied AMS shows strong P values coincident with directions of extensional tectonics structures (E1 and E2) which affected NW Iberia during the late Variscan times. All these data plus the fact that the most important maxima of the EGMA are located along the Viviero and Viveiró extensional detachments support that extensional tectonics was the key to magnetization. New EGMA models must include the role of these structures in the magnetization and take into account the conspicuos NRM of inverse polarity present in the all the analyzed samples.