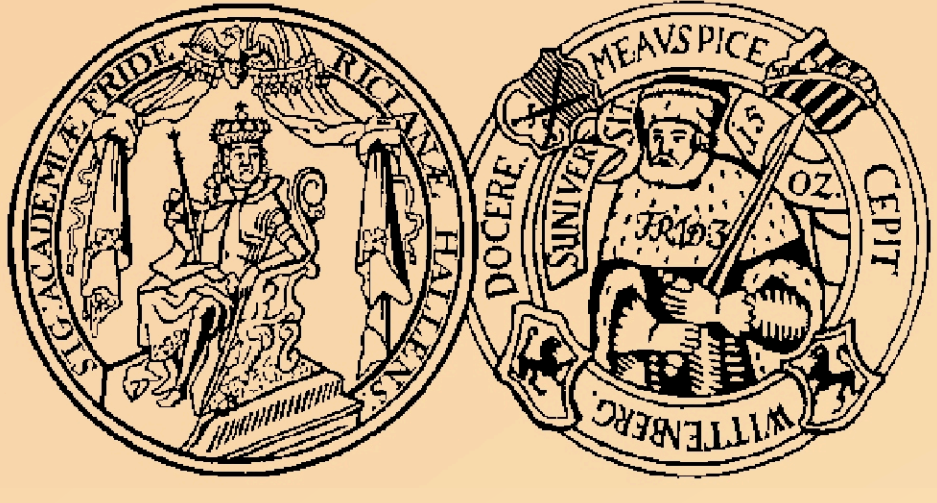


Cadomian, Ordovician and Variscan igneous events preserved in gneiss domes of the Central Pyrenean Axial Zone



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Polyorogenic Pyrenees

The present-day Pyrenees are an Alpine mountain chain, but the core of the Central and Eastern Pyrenees - the Axial Zone - is a result of the Variscan orogeny. Two main magmatic phases dominate the Axial Zone: Late Carboniferous granite plutons (e.g. Bassiès and Mont Louis-Andorra) and Middle Ordovician orthogneisses (e.g. Aston, Canigó). A recent study by Castiñeiras et al. (2008) has identified Cadomian age (~550 Ma) orthogneisses in the westernmost Pyrenees, at Cap de Creus.

The majority of modern geochronological data (U-Pb dating) are obtained from the Eastern Pyrenees, while the geochronology of the larger Central Pyrenees is still in its infancy (Table 1). The purpose of this study is to advance the knowledge of timing of magmatic and metamorphic events in the Central Pyrenees.

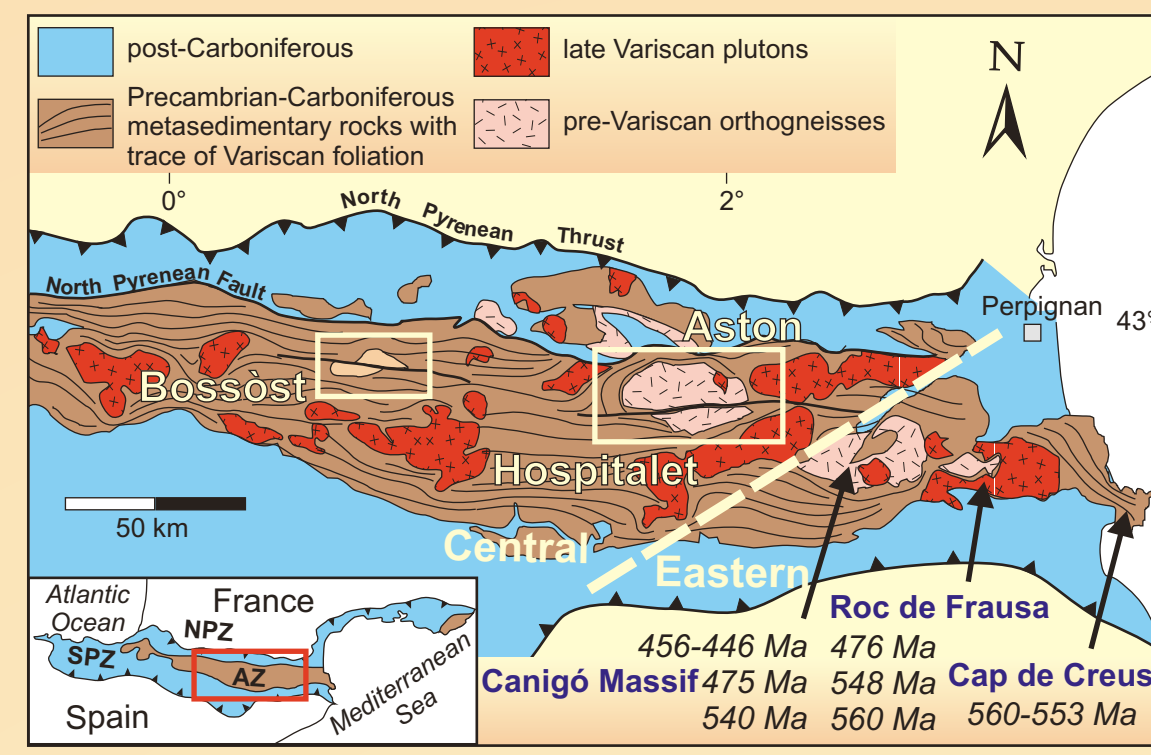


Fig. 1: Tectonic setting of the Central and Eastern Pyrenean Axial Zone with locations of the study areas and selected dated pre-Variscan rocks (see Table 1).

Scope of this study

Two major dome structures of the Central Pyrenees, the western Bossòst and the eastern Aston-Hospitalet domes are of particular interest. The geochronology of magmatic events of the Bossòst dome, a structural and metamorphic dome with a granitic core, has not been established yet. The core of the Aston dome comprises a variety of orthogneisses, some of them of middle Ordovician age (Denèle et al. 2009), others displaying signs of anatexis, possibly related to main Variscan igneous activities.

Migmatitic paragneisses underlying the orthogneiss in the western Aston dome may preserve contact metamorphism related to the initial emplacement of the magmatic precursors. Furthermore, the metasedimentary mantle of the western Aston dome is underlain by a widespread granitic dome of unknown age (Soulcem granite), emplaced at deeper structural levels, evident from high temperature contact aureoles, than the Bassiès or Mont Louis-Andorra plutons.

Table 1: Selection of U-Pb zircon ages of the Axial Zone

Eastern Pyrenees			
Canigó	Orthogneiss	475-446 Ma	SHRIMP, TIMS, Ion microprobe (Deloué et al. 2002, Cocherie et al. 2005, Casas et al. 2010)
Canigó, Nuria	Metatuff	581, 540 Ma	SHRIMP
Roc de Frausa	Orthogneiss	560 ± 7, 476 ± 5 Ma	SHRIMP (Castiñeiras et al. 2008)
Cap de Creus	Metatuff	560 ± 11 Ma	SHRIMP
	Orthogneiss	553 ± 4 Ma	SHRIMP (Castiñeiras et al. 2008)
Central Pyrenees			
Mont Louis Pluton	Granite	305 ± 5 Ma	Ion microprobe (Maurel et al. 2004)
Bassiès Pluton	Granite	312 ± 2 Ma	TIMS (Paquette et al. 1997)
Ax-les-Thermes	Granite	321 ± 7 Ma	Ion microprobe (Denèle 2007)

Methodology

Seven samples from the Bossòst (3) and the Aston (4) domes were crushed, subjected to magnetic and densimetric separation in order to obtain zircon and monazite grains. The grains were mounted in an epoxy resin, and cathodoluminescence (CL) images made with a JEOL microprobe show zoning and overgrowth sections in each zircon. U-Pb ratios were obtained by Laser Ablation method using a New Wave 213 (Nd-YAG 213 nm laser) and a Thermo-Finnigan Element 2 MC-ICPMS at the geochronology lab of the Institut für Geowissenschaften of the Johann-Wolfgang-Goethe Universität Frankfurt.

Bossòst Dome

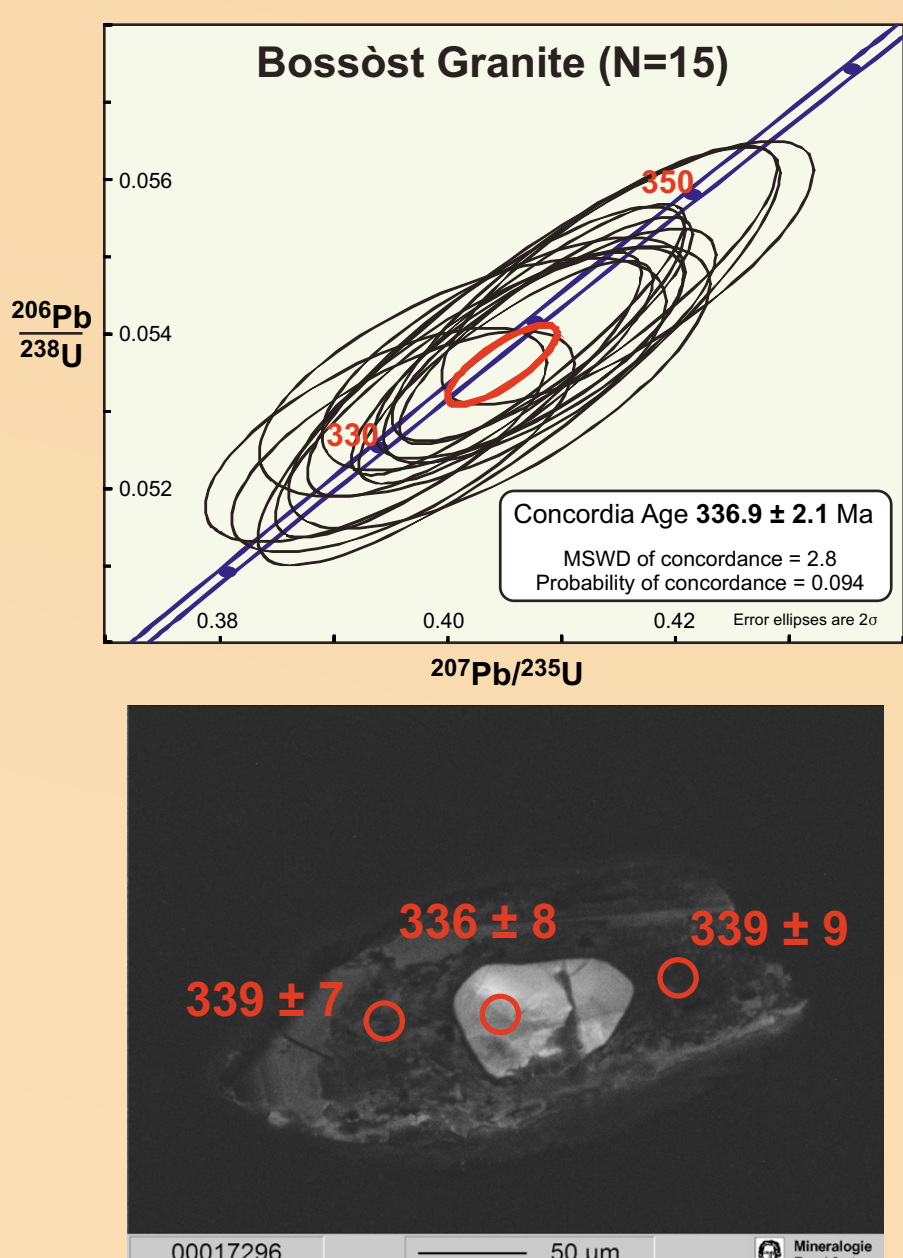


Fig. 3: Concordia diagram of 15 analyses from zircons from the Bossòst granite. Exemplary CL-image of a zircon with a highly radioactive rim (low contrast) and U-poor bright core. Mean concordia age and ellipses are computed with IsoPlot 3.41 (Ludwig, 2005). Spot sizes are indicated by red circle on CL image of zircon.

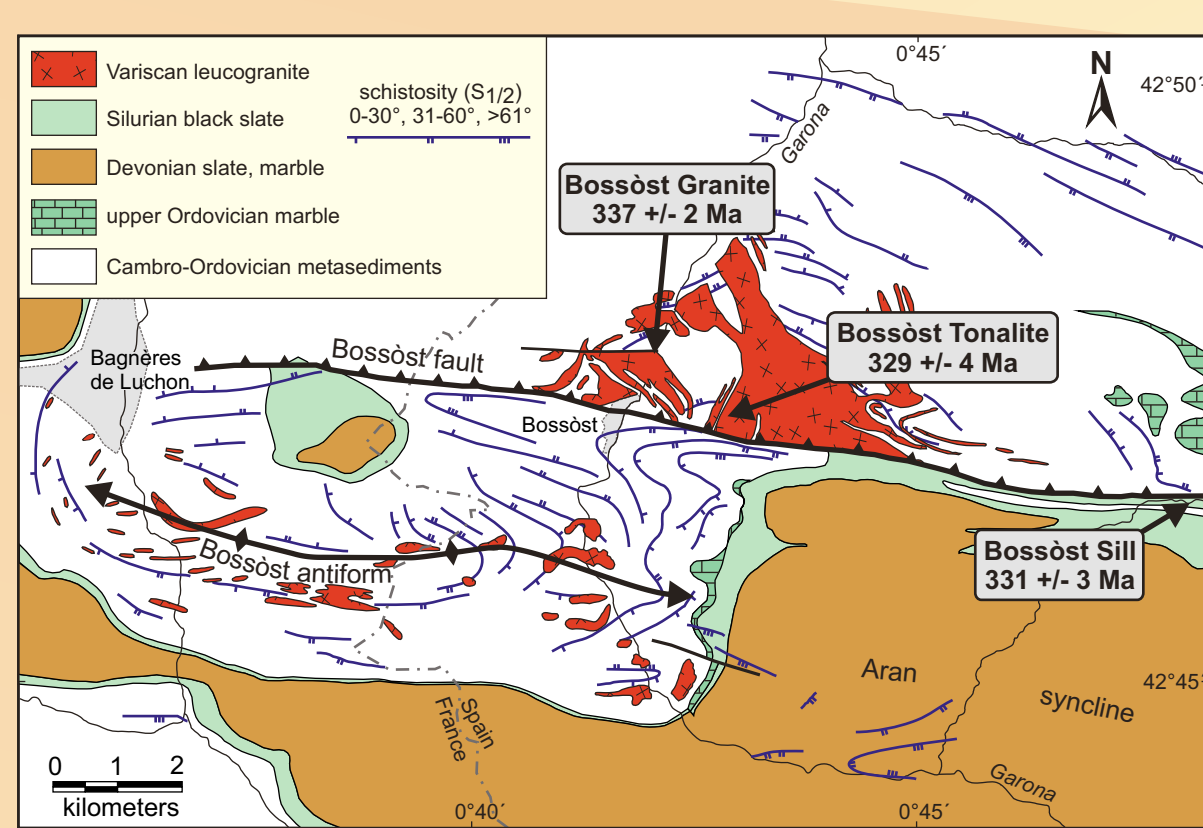


Fig. 2: Geological and tectonic map of the Bossòst metamorphic and structural dome. Modified after Mezger & Passchier (2003).

Bossòst Granite

The Bossòst granite is predominantly a leucocratic muscovite granite forming the core of the Bossòst dome, exposed in the northern half of the dome. The sample analyzed was taken north of the village of Bossòst (Fig. 2).

Long prismatic D- and F-type zircons, generally U-rich (> 600 ppm U), some less radioactive cores (Fig. 3), yield ages ranging from 344-330 Ma, averaging at **336.9 ± 2.1 Ma**. This is significantly older, by 20-30 My, than the shallow level Bassiès pluton further east.

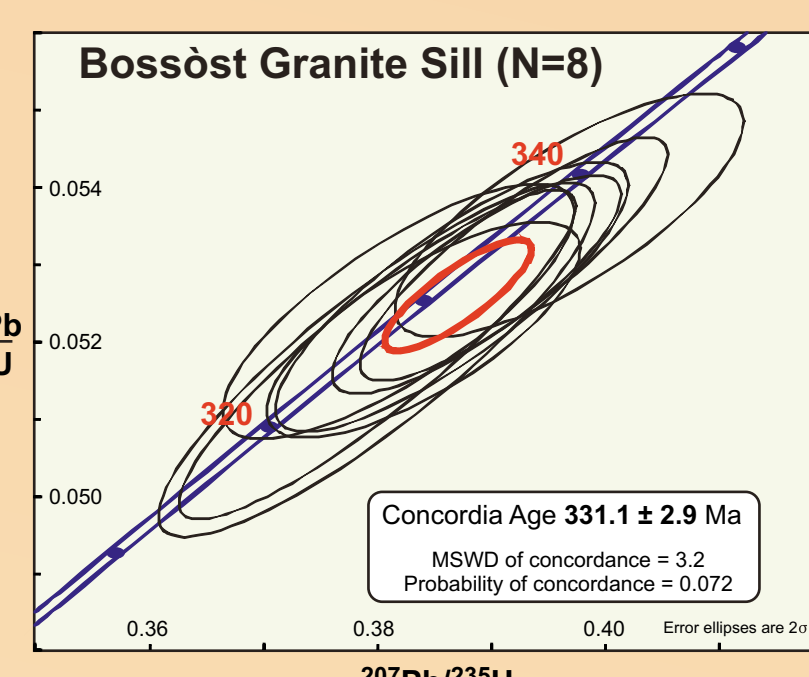


Fig. 4: Concordia diagram of 8 zircon analyses from the folded Bossòst granite sill (Fig. 4a). Zircons are highly radioactive, evident from the weak contrast in the CL image.

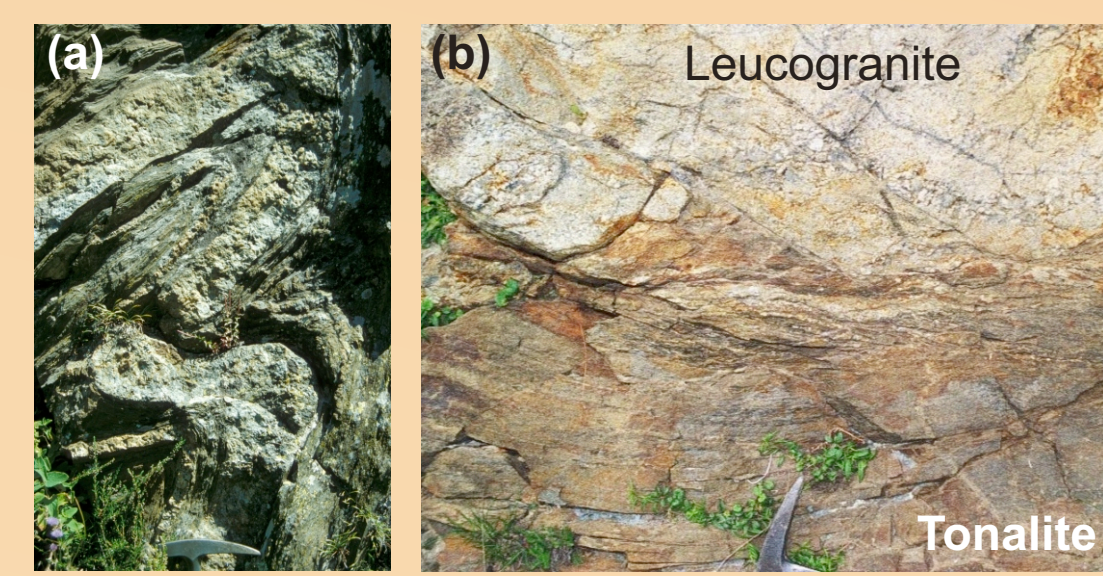


Fig. 4: Sample location of folded granitic sill within Cambro-Ordovician mica schist (a) and foliated tonalite in contact with brittle deformed leucogranite (b) in the northern Bossòst dome.

Folded granite sill

At the eastern end of the Bossòst dome, a muscovite granite, similar in composition to the Bossòst granite sample, intruded quartzitic mica schist. Both schist and sill are folded by F3 folds (Fig. 4a, Mezger & Passchier, 2003).

Separated zircons have various shapes (G1, L5, P5, S8), are brownish coloured or clear. All are highly radioactive (600-1200 ppm U). Concordant ages range from 337-325 Ma, averaging at **331.1 ± 2.9 Ma**, very similar to the main Bossòst granite (Fig. 5). Thus, F3-folding post-dates the middle Viséan.

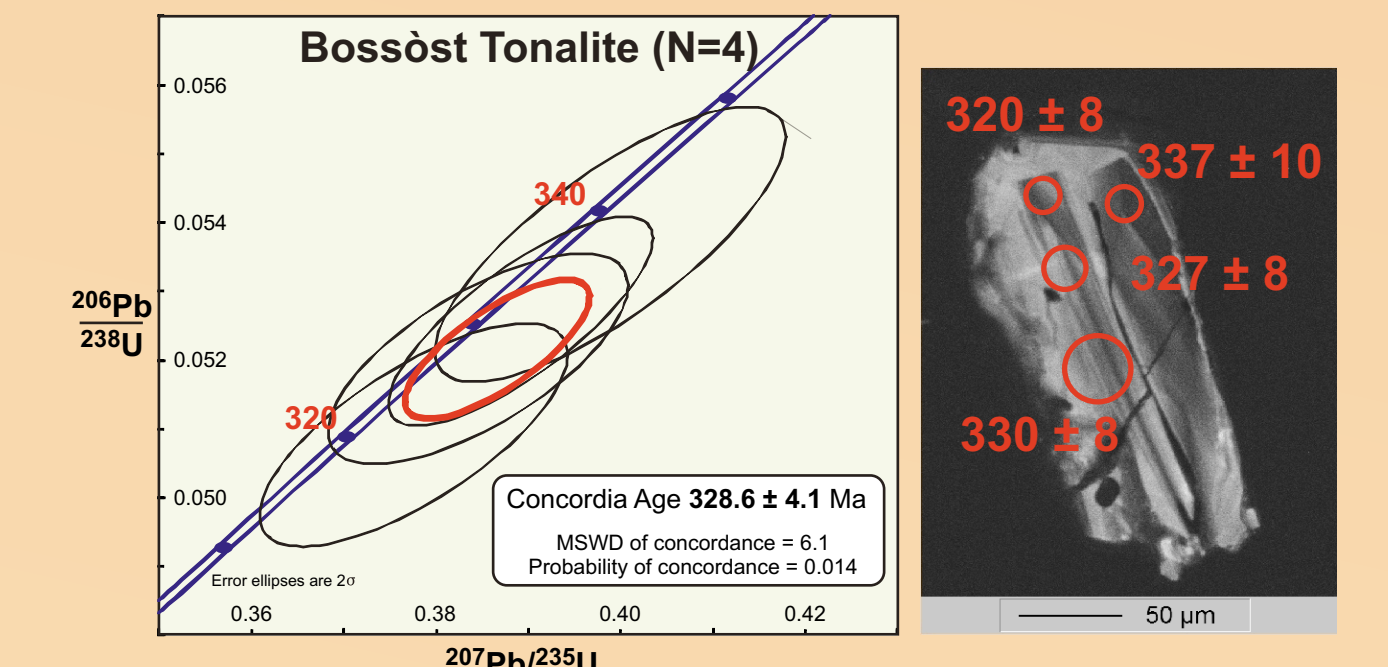


Fig. 6: Concordia diagram of four analyses from one zircon of the Bossòst tonalite.

Foliated tonalite

In the central core of the Bossòst granite, a foliated hornblende tonalite is in contact with massive leucogranite (Fig. 4b). Mezger & Passchier (2003) speculated that the tonalite could represent an older deformed gneiss, similar to the Ordovician orthogneisses of the Aston Massif. However, preliminary results yield an average age of **328.6 ± 4.1 Ma** (Fig. 6), within error of the Bossòst granite ages. Most likely, the tonalite represents a mafic fraction of the same magma that produced the granites. The observed deformation can be attributed to movement along the closely Bossòst fault.

Riete orthogneiss

A weakly foliated two-mica metagranite is exposed at the southern end of the Riete dam (Fig. 7). Partial anatexis is observed. Zircons are clear, prismatic (P1 and P2), and show strong oscillatory zoning or discordant overgrowth of an older core. Half of the analyses cluster at a concordia age of **466.1 ± 1.5 Ma** (Fig. 8), almost identical to the 471 Ma old augengneisses near the Mérens shear zone (Denèle et al. 2009). Older cores display inherited ages as old as 717 Ma, with minor clustering around **585 ± 5** and **644 ± 4 Ma**. These point to Cadomian (West African craton or local?) provenance of detrital zircons. Similar age distribution has been reported from the Roc de Frausa orthogneiss in the Eastern Pyrenees by Castiñeiras et al. (2008).

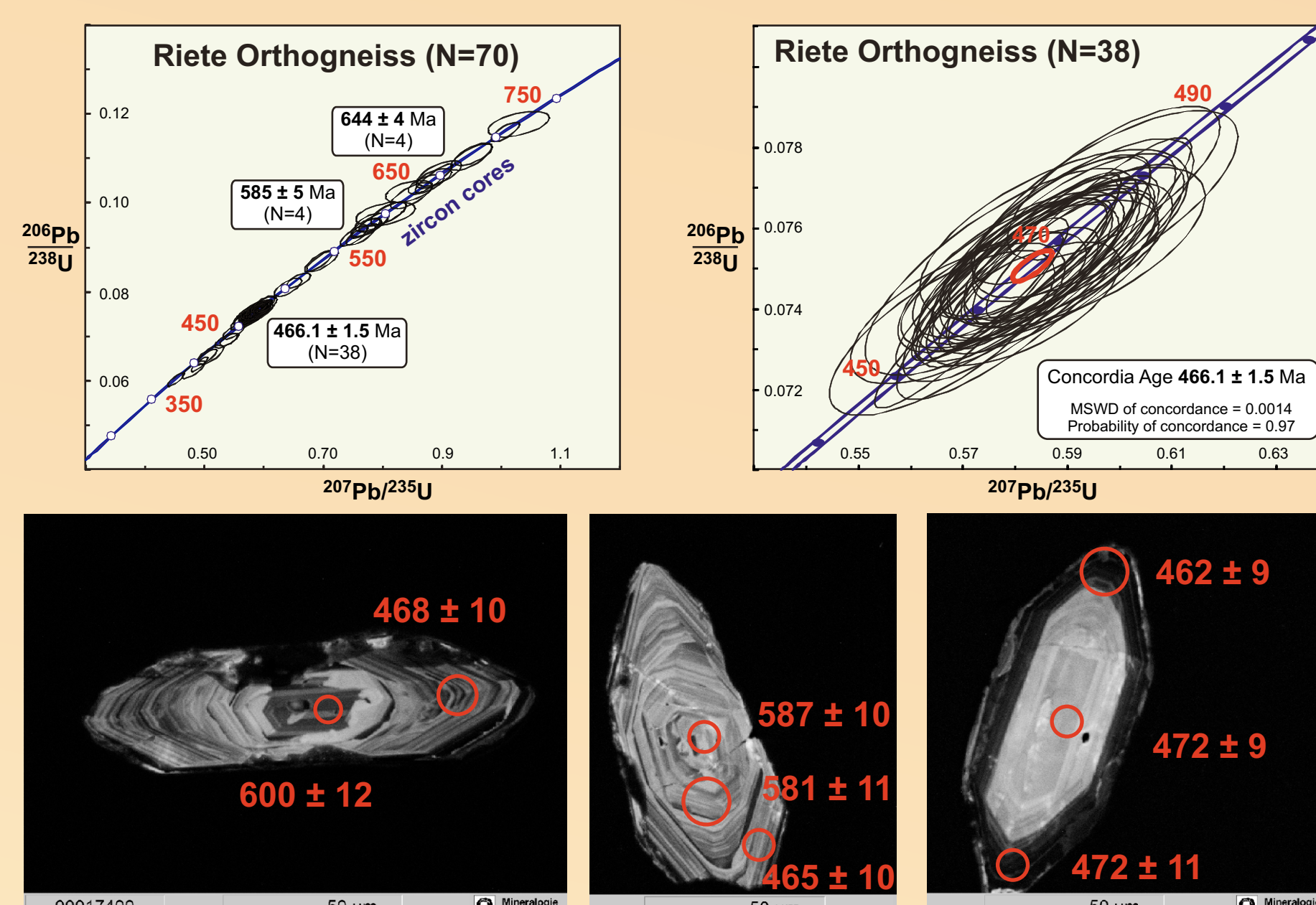


Fig. 8: Concordia diagrams of 70 analyses from zircons of the Riete orthogneiss. Half of the analyses yield middle Ordovician ages, in form of zircons crystallized at that time (right CL image), or as overgrowth on inherited cores of Cadomian age (central and left CL image). Pre-middle Ordovician ages are recorded in zircon cores.

Aston-Hospitalet Dome

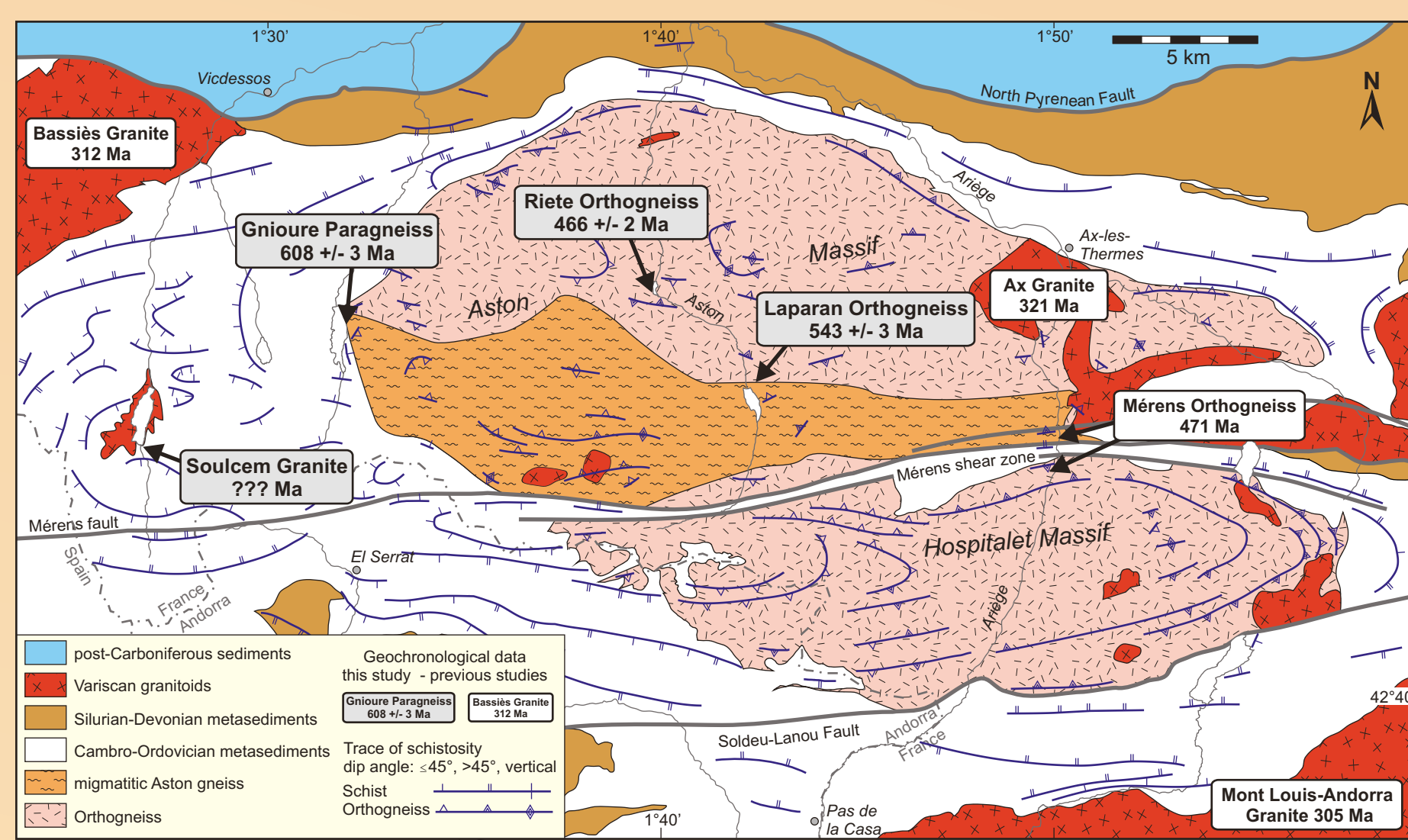


Fig. 7: Geological and tectonic map of the Aston-Hospitalet domes with sample location of rocks dated in this study and previously published U-Pb zircon ages. Modified after Mezger (2009). Question marks denote analyses yet to be processed.

Laparan orthogneiss

A medium-grained porphyric biotite granite, with signs of migmatization in the outcrop is found in the central part of the Aston gneiss dome (Fig. 7). Long prismatic (P4) zircons yield concordant ages ranging from 556-528 Ma, averaging at **542.5 ± 4.9 Ma**, the basis of the Cambrian (Fig. 9). No younger overgrowth rims have been observed (although a larger number of analyses need to be processed yet). These ages correlate well with the Port gneiss (553 Ma) at the Cap de Creus, the eastern termination of the Axial zone (Castiñeiras et al. 2008). So far, no tectonic event is correlated with a Neoproterozoic/Early Cambrian magmatic activity. A Cadomian basement, which has been rejected until recently, is becoming a possibility.

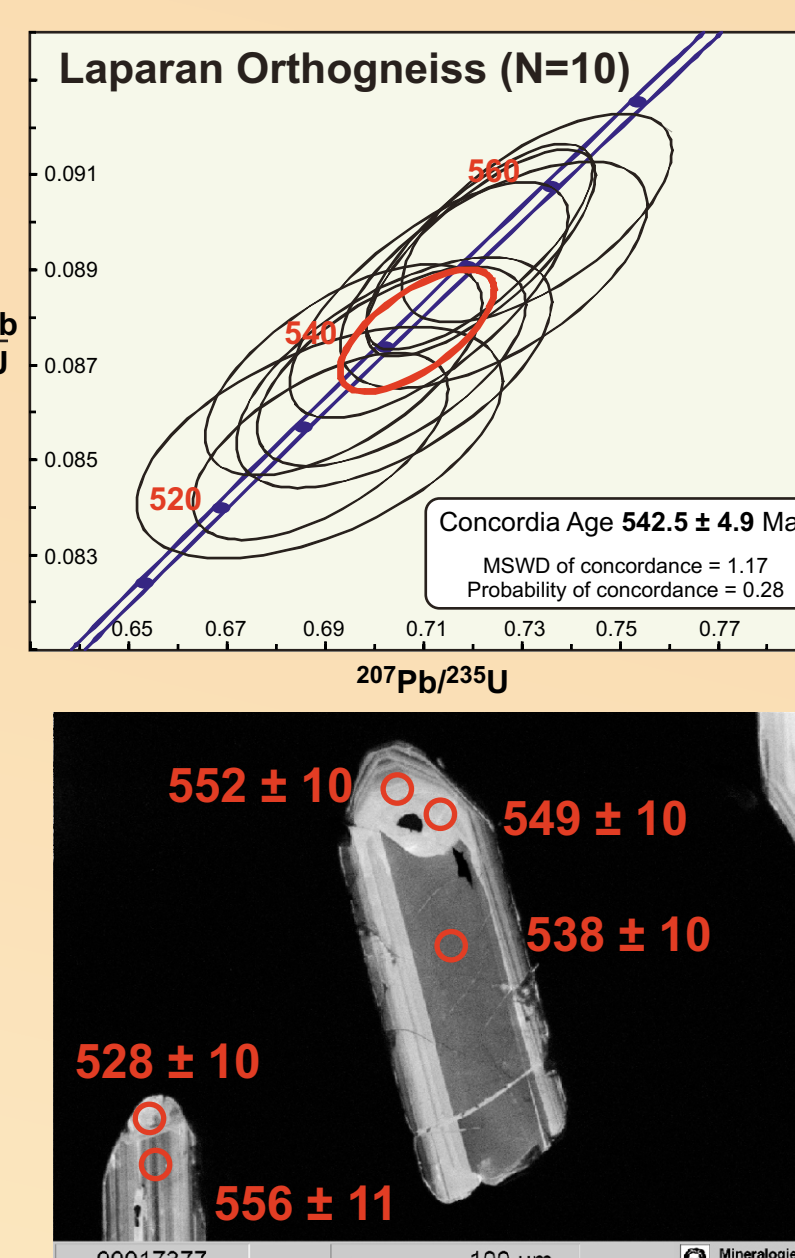


Fig. 9: Concordia diagram of 10 zircon analyses from a porphyric biotite orthogneiss, south of the Étang de Laparan. CL-image shows magmatically zoned zircons with comparable ages, within errors, of core and rim.

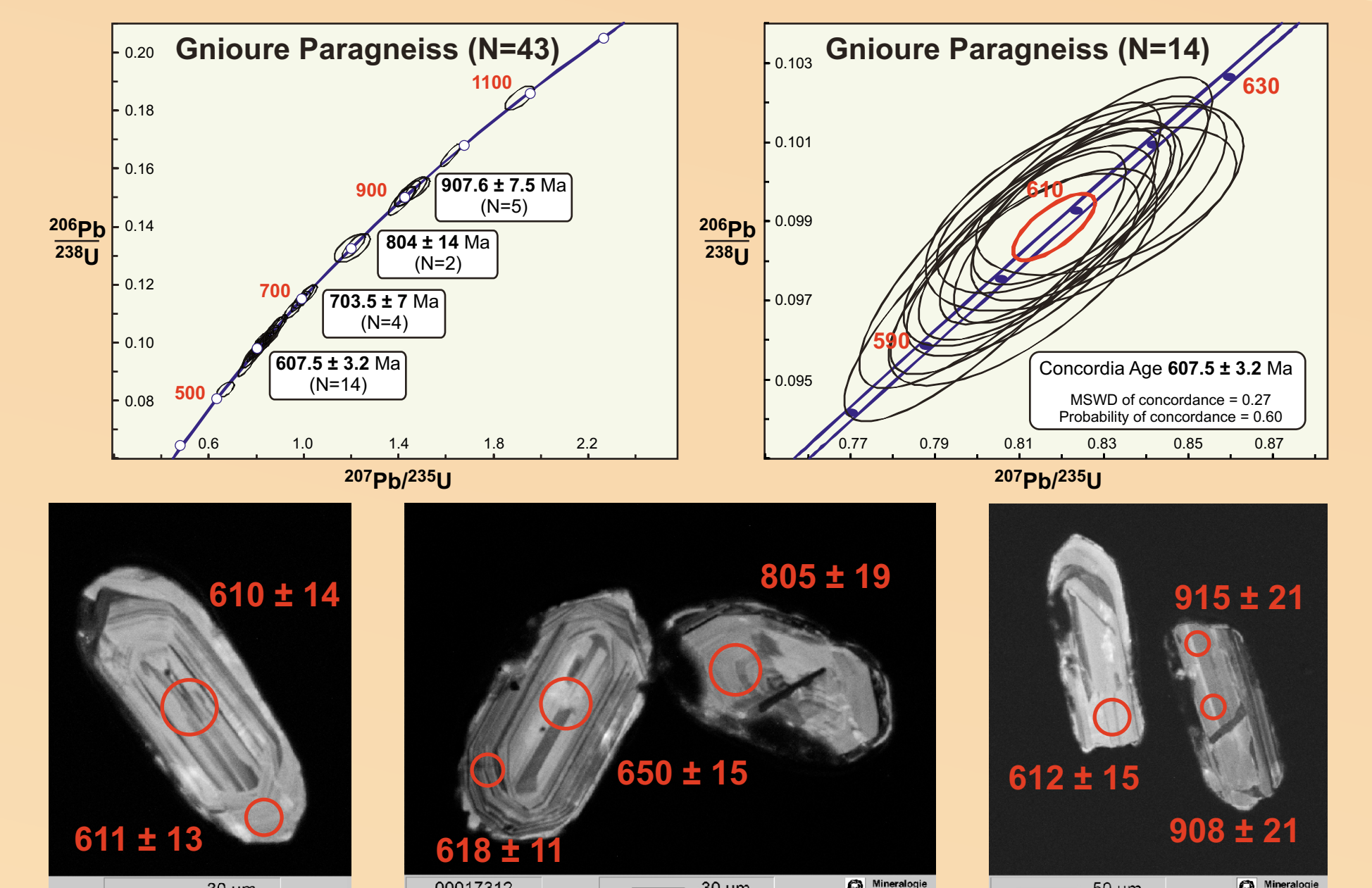


Fig. 10: Concordia diagrams of zircon analyses from the migmatitic Gnioure paragneiss at the western margin of the Aston orthogneiss. The rounded shapes of most grains indicate a detrital origin. Ages range from 517 Ma to 2.55 Ga (not shown here), with a clustering of one third of the ages at 607 Ma. Significant growth of younger rims around older inherited cores is not observed. Various ages reflect different provenance regions.

Gnioure paragneiss

At the western end of the Aston orthogneiss, migmatitic paragneisses, part of the metasedimentary mantle, structurally underlie orthogneisses at the eastern shore of the Gnioure lake (Fig. 7). Two zircon populations (type P1 and P2), mostly transparent, parallel and oscillatory zoned were separated. The obtained age spectrum ranges from **2.57 Ga to 519 Ma**. A larger cluster exists at **607.5 ± 3.2 Ma**. Older ages are not restricted to zircon cores, as in the Riete orthogneiss, but represent detrital zircons of different provenance regions. Similar age spectra are reported from the Cap de Creus metatuff (Castiñeiras et al. 2008).

The origin of migmatization may be resolved by future monazite dating, which allows to date high-grade metamorphic events, due to lower closure temperatures than zircons. Two scenarios are plausible: Contact metamorphism due to initial Early Ordovician emplacement of the orthogneiss protolith, or later main-phase Variscan regional metamorphism due to the widespread igneous activity which produced the Bassiès and Mont Louis plutons.

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Conclusions

The igneous events recorded in various magmatic rocks of the Pyrenean Axial Zone are more varied than envisioned just a few years ago. Cadomian magmatism is being established throughout greater parts of the Pyrenees. Main phase Variscan magmatism is not coeval. Either deeper intrusions are older, and/or Central Pyrenean plutons pre-date eastern intrusion.

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