Conference Report

The tectonic evolution of the Pyrenees: a workshop

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Report of a meeting of the Tectonic Studies Group held at the University of Cambridge on 21 May 1983.

About 70 geologists and geophysicists from Britain, France, Holland and Spain met to discuss the tectonic evolution of the Pyrenees and surrounding areas. Twenty short talks and 12 posters were presented and the meeting closed with a two-hour 'round table' discussion.

Hercynian geology and Alpine overprinting

Vielzeuf referred to lower crustal granulites of probable Hercynian age along the North Pyrenean Fault. Zircon age determinations for these rocks are in progress. In the Aston Massif, Vissers described the progressive folding and transposition of a steep early schistosity (suprastructure) into a relatively flat-lying attitude (infrastructure) with increasing metamorphic grade. The refolding accompanied low-pressure metamorphism and probably resulted from tectonic doming during granite emplacement. Similar low-pressure metamorphic rocks and granite pegmatoids in the Trois Seigneurs Massif were discussed in a poster by Wickham. Although comparatively few participants spoke on Hercynian orogenesis, it appears to have been characterized by unusually high heat flow and intense plutonic activity; the tectonic setting of the area at this time remains obscure.

Andrews, Austin and Colwill described high strains measured on pyrite-cube pressure-shadows in the Llavorsi syncline. These indicate up to 10 km of Hercynian S-directed thrust movement in this area. A similar reverse displacement with a dextral component on mylonites along the Merens Fault was described by McCaig and Miller. 39Ar-40Ar dating clearly shows this movement to be of Alpine age, and probably <70 Ma, although excess argon precludes a precise age determination at present. A major extensional mylonite zone of unknown age was described by Passchier in the St. Barthélemy Massif, and Pouget and Déramond reported mylonites in the northern part of the Axial Zone with an attitude similar to those of presumed Alpine thrusts. Clearly more radiometric work is needed to resolve the nature and extent of Alpine overprinting in the Axial Zone and North Pyrenean Massifs. Parts at least of the Axial Zone reached temperatures of 400–450°C in Alpine times (McCaig & Miller).

Mesozoic Evolution of the region and the North Pyrenean Fault

From the lower Triassic to the middle Cretaceous the North Pyrenean zone was an area of distension resulting in the creation of N- and S-facing margins separated by a trough (Souquet & Peybernès; Boillot). Boillot compared the S-facing European margin with the W Iberian margin, where major normal faults separate basement blocks, and serpentinite has been dredged from the continent–ocean transition zone. Normal faults may have been reactivated as thrusts during Eocene compression. To the N, subsidence curves show that the main periods of extension in the Aquitaine basin were Triassic to early Liassic and late Jurassic–lower Cretaceous, with a third phase at the end of the Cretaceous—beginning of the Tertiary probably due to flexural loading during convergence (Brunet).

In discussion, Boillot summarized the main movements of Iberia relative to Europe as follows: U. Jurassic–Aptian (140 to 110 Ma)—south-westward movement

110 to 75–80  Ma —400 km south-eastward movement

75–45 Ma —120–150 km north-westward movement.

The second two phases are constrained by magnetic anomalies. These movements caused a 35° anticlockwise rotation of Iberia relative to Europe between the Jurassic and the Eocene. Schott presented palaeomagnetic data on Triassic redbeds from the Barousse area which show that the former plate boundary corresponds to the North Pyrenean Fault. Elsewhere similar data are equivocal due to rotations during later tectonics and possible remagnetization. Vielzeuf suggested that Iherzolites were emplaced along the North Pyrenean Fault as a result of crustal thinning and alternating tensional and compressive stresses during the transcurrent second phase above. He compared the North Pyrenean Zone with modern oceanic transforms from which serpentinite is frequently dredged. Anderson presented gravity data in a poster showing the Lers peridotite to be a small body with its base just below the surface. In discussion, many participants were unwilling to speculate on the significance of the North Pyrenean Fault or its attitude at depth or even at the surface! Banda reaffirmed the seismic evidence for the presence of a 10–15 km MOHO step more or less under the North Pyrenean Fault. Gravity data (Williams & Fischer) conflicts with the seismic evidence, however, suggesting either a much smaller step or a very low crust–mantle density contrast. Banda favoured the latter explanation, although the seismic data are too noisy to confirm this interpretation. Some speakers (Williams, Graham) suggested that the trace of the North Pyrenean Fault may be allochthonous.

Geometry of the chain, nappe emplacement, shortening estimates

Boillot indicated that 100–150 km of shortening is to be expected in the Pyrenees from the amount of subduction in the North Spanish trough. Démamond, Graham & Hossack estimated 120–140 km shortening based on balancing of a thin-skinned interpretation of a cross-section through the Southern Pyrenees and Western Axial Zone. A
more conservative estimate of 60 km was given by Williams & Fischer, who discussed the geometrical problems of interpretation in which the thrusts steepen downwards. Both these speakers emphasized southward vergence in the chain, whereas Souquet and Peybernes presented a seismic section showing northward displacement of the Arize Massif by at least 7 km on a southward-dipping thrust, with significant displacements also on deeper structures. Beillard pointed out that thrusting in the N Pyrenees took place earlier than in the S.

Considerable interest was shown in the seismic sections and borehole data for the southern Pyrenean nappes presented by Megias and Rupelo. Palaeozoic basement is clearly involved even close to the nappe front, making gravity gliding an unlikely hypothesis for emplacement. Geometrical and sedimentological studies demonstrate a 'piggy-back' thrusting sequence (cf. also Dérand, Graham & Hossack). Superposition of nappes on E-W sections was interpreted (Megias) as due to E-W compression; other participants suggested this was more likely the result of southward movement of nappes across oblique ramps.

Several speakers stressed the close links between tectonics and sedimentation in the southern Pyrenees. Nijman described how the parallochthonous Tremp-Graus basin received sediment both from the Axial Zone to the N and the rising nappe front to the S. Palinspastic reconstruction indicates considerable anticlockwise rotation of this nappe during emplacement. Friend stressed the tectonic control of Miocene alluvial sedimentation and first reported detrital chloritized biotite derived from Axial Zone granodiorites in Upper Eocene/Oligocene fluvial sediments in the Huesca area. This constrains the time available for unroofing of the Axial Zone basement. A possible Miocene volcanic horizon (smectitic clay) was also reported. Puigdefabregas described 5 cycles of sedimentation in the Mesozoic and Tertiary, each related either to stretching or nappe emplacement.

Areas adjacent to the Pyrenees del Olmo, Riaza and Villanova showed how some of the major structures and the Cretaceous palaeogeography of the Pyrenees can be traced into the Basque–Cantabrian region. Guimera described structures in the Catalan coastal chains indicating three phases of Palaeogene compression: NW–SE in the lower-middle Eocene, N–S in the middle–upper Eocene (most important), and NE–SW in the late Oligocene. Similar structural trends throughout Iberia (Vegas) originated when deformation on the Pyrenean and Betics borders was transmitted to the interior of Iberia. Banda compared the geophysics of the Pyrenees and the Betics. The former are a narrow linear chain with a narrow band of weak seismicity. A sharp change in MOHO depth occurs at the North Pyrenean Fault, and the crustal root is centred under the topography. The latter are a more arcuate chain with an important band of seismicity with epicentres down to 120 km. The crustal root is displaced 40 km N from the topographic high and dramatically thinned continental crust or oceanic crust occurs to the S. These differences may reflect dominantly transient motion in the Pyrenees as compared with subduction in the Betics.

**Suggested further work** Much seismic work remains to be released: this should constrain nappe geometry and provide better estimates of shortening. Detailed and carefully controlled palaeomagnetic studies are needed, particularly for the Cretaceous. Further radiometric dating is urgently needed to resolve basement-cover controversies in the Hercynian belt and define the extent of Alpine metamorphism. Fission track studies on the uplift history of the chain have been started by Garwin (Cambridge). An analysis of sediment volumes derived from the Pyrenees would be helpful. A satisfactory model to explain crustal thickening in the Axial Zone and the creation and preservation of the MOHO step (if it exists) has not yet been produced.

It is hoped that another meeting on the Pyrenees in Spain or Holland may be held in two or three years’ time. Thanks are due to the chairmen, G. Boillot, W. Nijman, C. Puigdefabregas and E. R. Oxbergh, to all who were involved in organizing the meeting and the evening buffet/barbecue, and lastly to all the participants for contributing to a very enjoyable workshop. E. Banda is thanked for his critical comments on this report.

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Sediment production and sedimentary control of thrust sheet deformation along the Pyrenean margin of the Ebro basin P. F. Friend & J. P. F. Hirst (Cambridge).

Cretaceous palaeogeography of the Alpine phase in the Basque-Cantabrian area M. del Olmo, C. W. Riaza (ENIEP-SA) & M. Villanova (Elf-Aquitaine).

Compression direction during Palaeogene in the NE part of the Iberian plate J. Guimerà (Barcelona).

The Pyrenees and the intraplate deformation of Iberia R. Vegas (Madrid).

Betics-Pyrenees: a geophysical comparative study E. Ban (Zurich/Barcelona).

Geometrical problems of Pyrenean deformation G. D. Williams & M. Fischer (Cardiff)

Rôle du socle dans l'évolution tecto-sédimentaire des Pyrénées durant le Mésozoïque P. Souquet & B. Peybernès (Toulouse).