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The Internal–External Zone Boundary in the eastern Betic Cordillera, SE Spain: Reply

LIDIA LONERGAN

Department of Geology, Imperial College, Royal School of Mines, Prince Consort Road, London SW7 2BP, U.K.

JOHN PLATT

Department of Geological Sciences, University College London, Gower Street, London WC1E 6BT, U.K.

and

LIAM GALLAGHER

Network Stratigraphic Consultants, Unit 57, The Enterprise Centre, Cranborne Road, Potters Bar, Herts EN6 3DQ, U.K.

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In their discussion of our paper, Martín-Martín *et al.* raise a number of points that we will address individually. Their main contention appears to be with our overall interpretation of the Oligo-Miocene sedimentation and its relationship to the contact between the Internal and External zones in the Rio Pliego area on the north side of the Sierra España. They do not believe that the Oligocene–Miocene sediments were deposited in one evolving basin and they consider that the contact between the Internal and External zones is affected by N-directed strike-slip faulting in middle Miocene times.

Regarding the Amalaya Formation, Martín-Martín *et al.*, quoting Martín-Pérez *et al.* (1994), confirm our age determination for this formation of late Oligocene to early Miocene (Aquitanian). Contrary to their affirmation that only Malaguide clasts are found in the sandstones and conglomerates of this formation, Rivière *et al.* (1980), Lonergan (1991) and Lonergan & Mange-Rajetzky (1994) report the first occurrence of metamorphic detritus within the Tertiary succession of the Sierra Espuña within this formation. In addition to metamorphic rock fragments, epidote, chloritoid, staurolite, kyanite, andalusite and garnet grains were found within the heavy mineral assemblages in coarse sandstone beds from the Amalaya Formation (Lonergan & Mange-Rajetzky 1994). These metamorphic minerals are not known to occur within rocks of the Malaguide Complex in the eastern Betics and hence their occurrence within the Amalaya Formation turbidites indicates that metamorphic rocks of the Internal Zone (including the Alpujarride Complex) were exposed in the hinterland to the Oligo-Miocene basin.

Overlying the Amalaya Formation Martín-Martín *et al.* divide the formation that we have called the Bernabeles Formation into two formations ('early Burdigalian deposits' and 'late Burdigalian–Serravallian deposits' on their fig. 1) and they propose that the early Burdigalian deposits do not outcrop above the Amalaya Formation to the northeast of Palomeque. Because they recognize different detritus in the coarse-grained sandstones and conglomerates of these deposits, they argue that all three formations were deposited in different basins. We disagree with this interpretation for the following reasons.

(1) As described in Lonergan *et al.* (1994) a stratigraphic transition between the Amalaya Formation (with red marls) and overlying Bernabeles Formation rocks (with green marls) can be observed at localities 915 in the Amalaya area, and localities 1120 and 1144 in the area to the northeast of Palomeque (see fig. 3, Lonergan *et al.* 1994). Nannoplankton assemblages give the same age for this stratigraphic transition both to the southwest and northeast of Palomeque and it would hence appear that the lowermost units of the Bernabeles Formation are the same in the two areas.

(2) In the southwest of the area under discussion both groups of authors agree that the External Zone rocks are thrust over early Miocene rocks of the Bernabeles Formation, but to the northeast of Palomeque younger Miocene rocks outcrop. Martín-Martín *et al.* state that the *Spenolithus belemnos* biozone of 'upper early Burdigalian age' is missing (presumably in the area to the northeast of Palomeque) but they give no details nor map of their sampling locations. In this area there is no one single continuous stratigraphic succession exposed

throughout the whole formation, and there are at least two intraformational thrusts (fig. 4., Lonergan *et al.* 1994), so without knowing where they sampled it is difficult to assess the validity of their statement. In fact the presence of *Spenolithus belemnos* in our sample 1191B (Lonergan *et al.* 1994, fig. 5) indicates that zone CN2 (Okada & Bukry 1980), which is approximately equivalent to Zone NN3 (Martini 1971), is indeed present in the area. Despite the lack of continuous outcrop and the presence of thrusts, the nannoplankton assemblages found in samples distributed throughout the Bernabeles Formation do not indicate any major gaps in sedimentation of any tectonic significance. Within the resolution of our biostratigraphic data, the ages we obtained are consistent with a continuous stratigraphic section.

(3) Given that there are no angular discordances within the Amalaya and Bernabeles Formations, nor major stratigraphic unconformities, it is very difficult to see how the Oligocene to Miocene rocks can have been deposited in different basins. From a sedimentological viewpoint both the Amalaya and Bernabeles formations are very similar consisting of deepwater pelagic marls interbedded with sandstones, calcarenites, conglomerates and slumps deposited by turbidity currents and mass gravity flows. As described in detail by Lonergan & Mange-Rajetzky (1994), a gradual change in detritus within the clastic units is observed within these formations through time. The Late Oligocene sandstones and conglomerates are mainly sourced from Malaguide rocks with minor input from metamorphic rocks in the hinterland. By Burdigalian times exhumed Internal Zone metamorphic rocks were providing large amounts of detritus to the basin as indicated by the metamorphic minerals dominating the heavy mineral assemblages. The youngest rocks of the Bernabeles Formation that we studied were of Langhian age, and at this stratigraphic level Lonergan & Mange-Rajetzky (1994) found a few grains of high-pressure metamorphic minerals within the heavy mineral suite. Hence a complete unroofing sequence of the Internal Zones is preserved within the Amalaya and Bernabeles Formations. The upper parts of the Bernabeles Formation (Langhian levels) onlaps the Subbetic and it is possible that minor amounts of carbonate detritus from the External Zones as well as Internal Zone clastic detritus were being supplied to the basin at this time. Despite published evidence for metamorphic detritus in the Bernabeles Formation (Lonergan & Mange-Rajetzky 1994) Martín-Martín *et al.* say that the late Burdigalian to Serravallian deposits were fed by detritus from the External Zones and hence occupied a 'new and different basin'. A simpler interpretation of the field data which integrates the structural, sedimentological and stratigraphic observations is that during the late Oligocene to the middle Miocene the deepwater rocks of the Amalaya and Bernabeles Formations were being deposited in a tectonically active piggy-back or foreland basin at the site of oblique convergence between the Internal and External Zones (Lonergan 1993, Lonergan & Mange-Rajetzky 1994). On the southwest edge of this basin the Subbetic is thrust over early Miocene deposits, but further north in the same basin the middle Miocene sediments onlap the External Zones and the shortening is transferred onto the thrusts outcropping within the Bernabeles Formation. Palaeomagnetic data reported in Allerton *et al.* (1993) indicate that rocks of the Malaguide Complex in the Sierra Espuña were rotating clockwise between the late Oligocene and late Miocene. The rotations are consistent with the dextrally oblique convergence suggested by the kinematic data along the Internal External Zone Boundary. If the Sierra Espuña was rotating as it converged obliquely with the Subbetic, the basin in which the Oligo-Miocene sediments were being deposited may have been dramatically changing shape during the same time interval. Hence the southern end was underthrust beneath the Subbetic while the northern end opened out and made space which was infilled by the early–middle Miocene sediments which finally onlapped the Subbetic. The detritus being supplied to the basin evolved as successively deeper levels within the Internal Zone were exhumed.

Strain partitioning in a tectonic regime of oblique convergence may result in the formation of a few local strike-slip faults, such as the one identified by Martín-Martín *et al.* in their fig. 1 (which incidentally appears to be the same fault as that located at D in fig. 6, Lonergan *et al.* 1994). The majority of the structures observed by us along the Internal External Zone boundary are most consistent with oblique shortening along a thrust fault zone than with strike-slip faulting as proposed by Martín-Martín *et al.*

As a final point, Lonergan (1991) chose the name Amalaya Formation because the sections logged by previous workers through these rocks (e.g. Paquet 1969, Rivière *et al.* 1980) were undertaken along the dry stream section named the Barranco de la Amalaya on the 1:50,000 Military Topographic map (Coy, number 25-37). No previous workers had formally named the formation. The confusion between Amalaya (Lonergan *et al.* 1994) and Almoloya (Martín-Martín & Martín-Pérez *et al.* 1994) appears to arise because the farmhouse in the same area is called Cortijo Almoloya.

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