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Opening of the Alboran Sea

THE Alboran Sea contains two basins deeper than 1,000 m separated by a ridge which we shall call the Alboran marginal fracture (Fig. 1). Seismic reflexion studies and data from the Joides drill site 121, situated exactly on the northern limit of the western basin, show that the deepest sedimentary layers, lying on the substratum, are older than upper Burdigalian (14 m.y.), but probably younger than lower Aquitanian (23 m.y.)[1]. But we do not know whether the substratum of the deep basins is young oceanic crust or foundered continental crust. Here we shall assume that the portions of the basins deeper than 1,000 m indeed consist of new surface created by the separation of two rigid plates during the Middle Miocene, and we shall discuss whether the structure is geometrically compatible with such an opening.

If such a rigid opening occurred, it should be possible to reconstruct its geometry by identifying the transform faults.

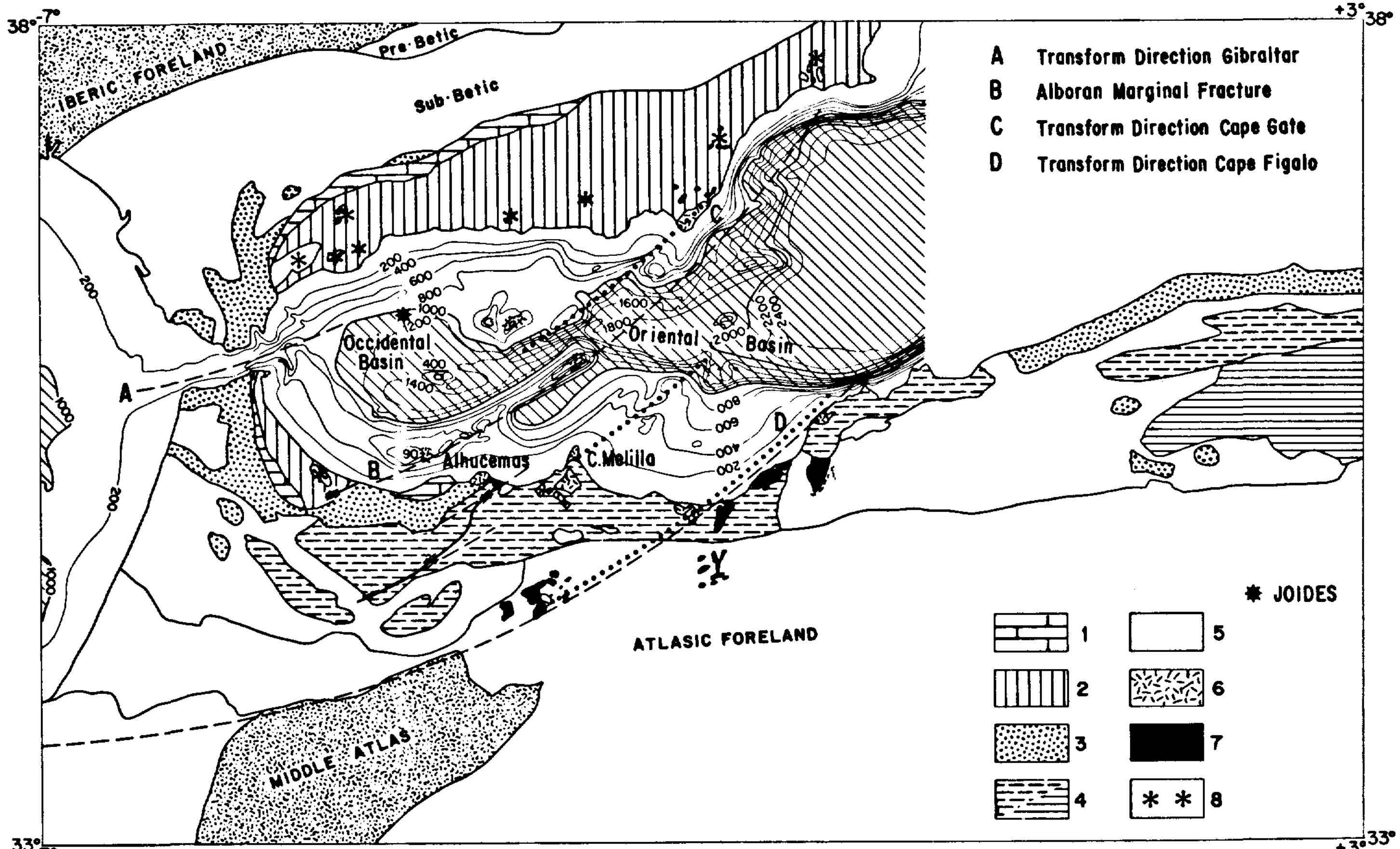

Fig. 1 Bathymetry of the Alboran Sea after Olivet *et al.*[9] and simplified structural map of the adjacent continents after Andrieux[1]. Dotted lines indicate the lineations at which andesitic volcanism is found. *A*, *B*, *C* and *D* are small circles about the pole of rotation (see text). 1, Calcareous belts (internal zone); 2, Palaeozoic units (internal zone); 3, flysch nappes; 4, schist zone (external zone); 5, external nappes; 6, andesitic outcrops; 7, Plio-Quaternary basaltic outcrops; 8, basic and ultrabasic outcrops ("roches vertes").

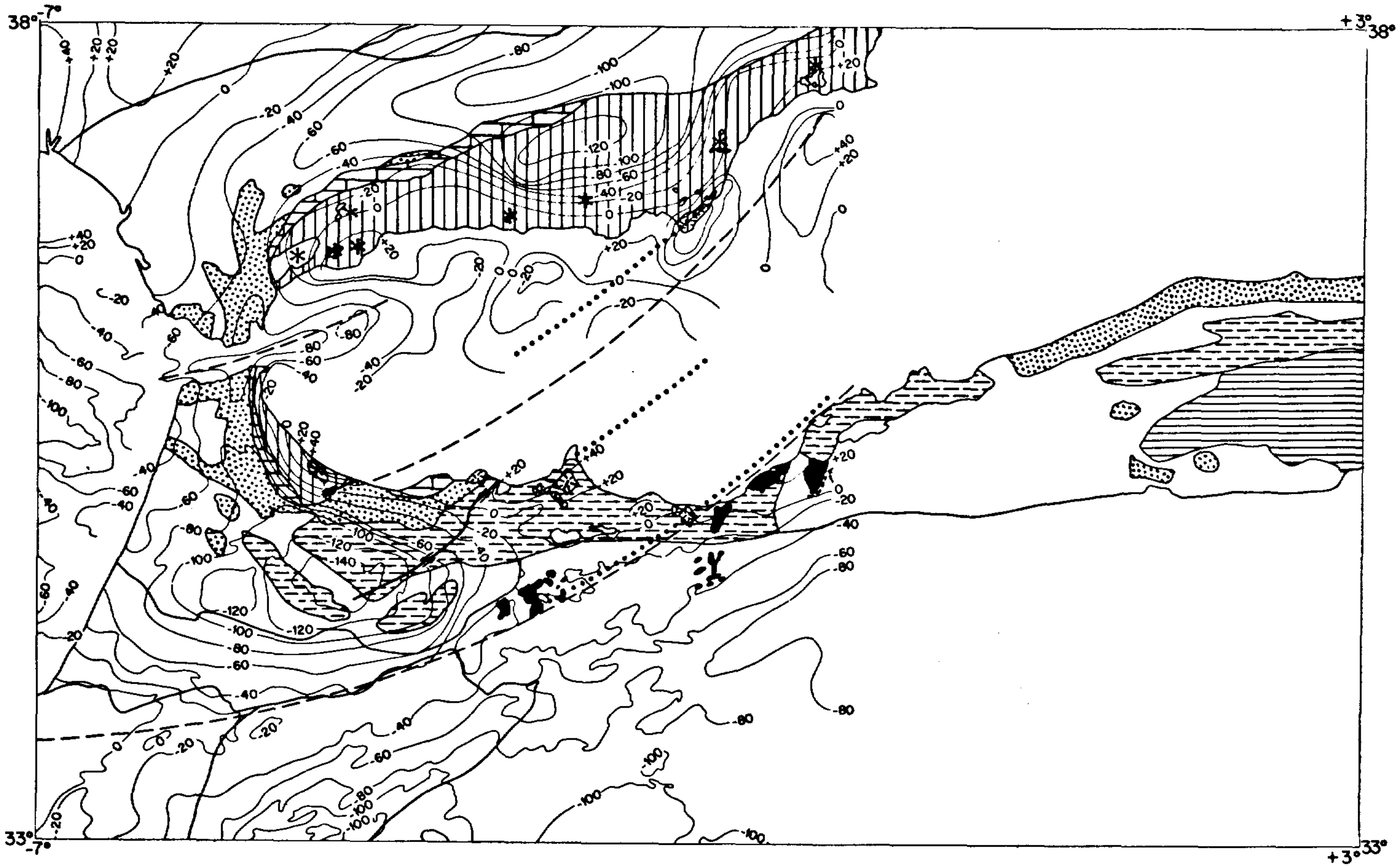

Fig. 2 Gravimetric map. Free air anomaly over the sea and Bouguer anomaly over the continent. Note the negative trough along Gibraltar Straits.

First, we note the existence of the large WSW–ENE Alboran marginal fracture (*B* in Fig. 1), on which there has been andesitic volcanism on the island of Alboran and on the Tofino and Xauen banks[2]. Second, there is a corresponding bathymetric feature (*C* in Fig. 1) running from Cape Gate to Djibouti bank through Chella bank. Andesitic volcanism also occurs along this line, and has been dated as Helvetian–Tortonian in Cape Gate[3].

These two alignments are roughly parallel, and they can be juxtaposed by closing the basin along this direction. Therefore it is tempting to consider these features as corresponding parts of the same transform fault created during the opening of the sea. In fact the Alboran Ridge is typical of marginal fracture ridges, as defined by Le Pichon and Hayes[4], which are created during the early stages of opening by the shearing of two portions of continental crust.

Are there other structural directions which are compatible with such an opening? Fig. 2 is a gravity map, combining Bouguer anomaly on the continent with free air anomaly on the sea, and it shows a deep negative trough along the general line of the Gibraltar Straits. This gravity trough is not solely due to the topography since it does not disappear with the Bouguer correction. The direction of the trough is marked *A* in Fig. 1. If the three directions just described are transform faults, they must correspond to small circles about the same pole of rotation. A least squares computation yields a pole at 40.5° N, 7.4° W, with a small standard deviation. Lines *A*, *B*, *C* are computed small circles about this pole. The reader can judge the quality of the fit.

We note next that the theoretical small circle *D* follows a line which in its northern part corresponds to the offset along the continental margin of the Tellian structure. To the south, the line is marked by mostly basaltic Plio-Quaternary volcanism, which probably indicates a line of fracture[5]. The southern boundary of the Riff tectonic structure follows this line, as shown in the gravity map (Fig. 2).

Finally, another alignment can be recognized passing through the andesitic volcanism of Cape Melilla and through a large caldera (Cabliers Bank) described by Giermann *et al.*[2]. A strike slip fault active during Middle Miocene, which has been described by Andrieux[1], lies along the southern prolongation of this alignment.

Fig. 3 shows what happens when the Alboran basins are closed by moving the "Riff" plate relative to the "Betic" plate about the computed pole. We assume that the differential motion between the Riff plate and the African platform occurred along line *D*. The offset between the Riff and Tell tectonic structures then disappears and there is a remarkable

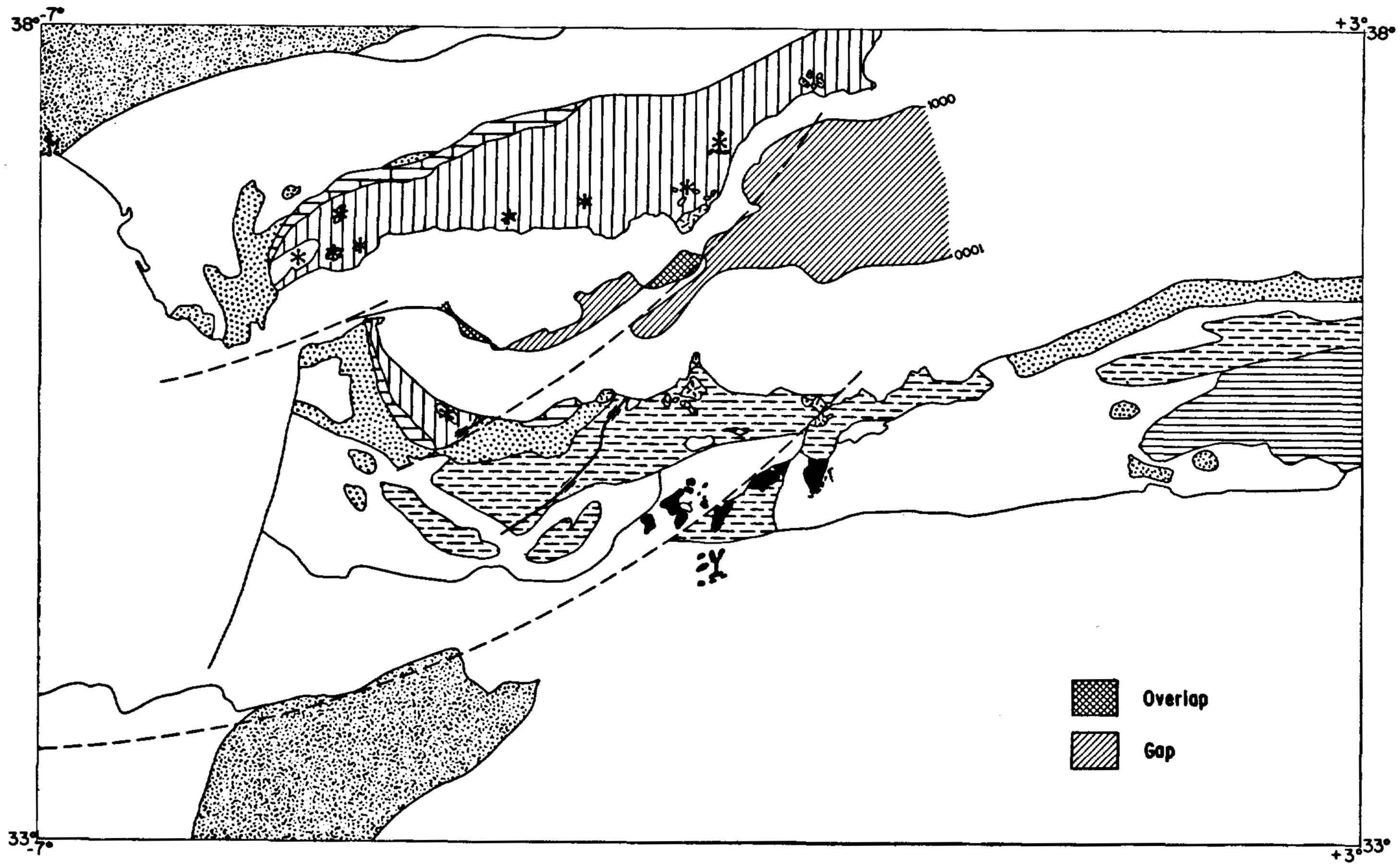

Fig. 3 Palaeogeometry in Lower Miocene before the opening obtained by closing the part of the Western Alboran basin deeper than 1,000 m about the pole *P*. Note the continuity of the fundamental schistous units of the Riff and the Atlasic forefront in Northern Algeria.

east–west continuity.

We have not yet defined the western boundary of the Riff plate. The geometry requires that a consuming plate boundary existed somewhere to the west of Gibraltar and it suggests that line A in Fig. 1 is a ridge-arc transform fault.

The time of opening is most probably lower Middle Miocene, on the basis of the age of the basins and of the andesitic volcanism. We feel that this is compatible with the known sequence of nappe movements[1,6]. This hypothesis is compatible with the Alboran plate hypothesis of Andrieux *et al.*[7] provided that this plate broke in two parts towards the end of the Miocene tectonic episode.

If our hypothesis is correct, it proves that the rigid plate concept holds even within actively tectonic regions and with plates only a few hundred km across. The opening described here occurred behind the Betico-Riffan arc, at the end of the principal phase of compression. It may consequently be compared with the formation of marginal basins behind an active island arc, as suggested by Karig[8] for the basins behind the Tonga–Kermadec and Marianas island arcs.

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