ISLAND ARCS AND THE ORIGIN OF FOLDED RANGES

JAN H. BRUNN[1] & PIERRE F. BUROLLET[2]

ABSTRACT

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It is attempted to reconsider the problem of orogeny through a review of three arcuated systems: Tyrrhenian, Aegean, and Ceram.

The Tyrrhenian Sea is inherited from a sheaf of Alpine ridges and furrows located between the Corso-Sardinian block to the west and the African-Adriatic platform to the south and east. The abyssal plain represents the tearing apart of these zones following the gradual curving of the Calabro-Lucanian arc.

The Aegean Arc is part of the Hellenic-Tauric ranges. Its folding and thrusting is not due to the northward movement of a 'Tethysian plate', but to an active, outward thrust over its foreland. The Aegean bulge results from the westward movement of Anatolia, being barred to the west by the eastward thrusting Calabro-Sicilian Arc. The frontal trenches rising towards the south to the so-called Mediterranean Ridge should be compared to the mollassic furrows that surround all arcuated folded ranges.

The Banda Sea may correspond to a longitudinal extension similar to that of the Tyrrhenian Sea: it would be due to a compressional effect related to the north-westward movement of Australia. Transcurrent faults play an important role with two main directions, both being left-lateral: NNW or NW and E-W.

The interest that was stirred by the studies of island arcs, especially those of Van Bemmelen, was largely caused by the notion that these present day structures offer an image of the growth of folded ranges, of an orogen in the early phases of its development.

Plate tectonics, somewhat obscured the view by focusing attention upon subduction phenomena conceived and represented in vertical planes, seismic and gravimetric data being obtained precisely along such vertical sections. Further its excessively actualistic outlook often led to underrate the changes in mechanisms that occurred from the beginning of an orogenic cycle to its end. An attempt is made here to reconsider the problem of orogeny through a review of three arcuate systems: Tyrrhenian, Aegean, and Ceram, in the light of recent knowledge on oceanic and deep-sea geodynamics.

[1] Laboratoire de Géologie Historique, Faculté des Sciences, 91405 – ORSAY, France.

[2] Compagnie Française des Pétroles, 39-43 Quai André Citroen, 55739 – PARIS Cedex 15, France.

The Tyrrhenian Sea

The Tyrrhenian Sea is known for the complexity of its physiography and the variety of elements participating in its structure. Like the Alboran and the Aegean Sea it is included within the Alpine system, as opposed to the Ionian or the Eastern Mediterranean basins that are external to the range. The triangular shape of the surrounding coastlines bordered by their narrow continental shelves, is repeated at various depths, that is realising a succession of concentric steps leading to the main deep (3550 m). The latter has an oceanic crust with a thin sedimentary cover and a few sharp volcanic cones that are also to be found along the marginal steps. More detailed descriptions are given in SELLI ET AL. (1970), MORELLI (1970) and FINETTI & MORELLI (1973).

Various tectonic interpretations have been proposed, stressing the diverging symmetry of the Apennine on one hand and the Sicilian-Tunisian unit on the other. The following reflections are based upon new information bearing either on geology (OGNIBEN ET AL., 1975 'Structural model of Italy'; recent works of CAIRE, 1975, 1978; BOUSQUET, 1973;

DUBOIS, 1970, etc.) or on geophysical data obtained in particular through deep seismic surveys (GIESE & MORELLI, 1975; MORELLI ET AL., 1977; HIRN & SAPIN, 1976) or through magnetism and palaeomagnetism (ALVAREZ. 1972; STOREVEDT & PETERSEN, 1976; WESTPHAL ET AL., 1976; IACOBUCCI ET AL., 1977).

To the eastern and southern parts of the Tyrrhenian Sea, the mobile group, comprising the Apennines and Sicily, faces cratonic units of the African platforms: Pelagian and Ionian Seas to the south and east, Apulian and Adriatic 'Promontory' to the northeast. In fact, the latter also comprises the outer Hellenic and Dinaric zones. Moreover, its original size was reduced to an unknown extent through the converging thrusts of the closing Dinaric-Alpine-Apenninic Arc, while the whole system conflicted with the European Craton on its Alpine front (CAIRE, 1978).

The displacement of Africa relative to Europe must have included a fairly important northwestward trend. The cratons themselves underwent but small deformations, at least outside of the limits of the Alpine orogene, especially in Europe.

In the African block, the north-south lineaments and the distended grabens of Eastern Tunisia and the Pelagian Platform show only very slight horizontal displacements. The Gafsa fault, which may be followed towards the southeast, is associated with a strike-slip displacement of only a few kilometres. However, the Tunisian Atlas and the Saharan Atlas of Algeria contain important curved lineaments of NE-SW direction, that may correspond, according to CAIRE (1975), to left-lateral relative displacement. In the Apenninic-Adriatic area, similar faults are observable both in allochthonous and autochthonous units. They have, on the whole, N-S to NE-SW orientation; a late ESE-WNW fracture, apparently left-lateral, seems to cut across the whole peninsula, from Savona to Monte Gargano (Fig. 1).

There is a continuous transition between the Sirte Basin of Libya and the abyssal plain of the the Ionian Sea, which is linked in the same way to Corfu and the Puglia Platform (BUROLLET ET AL., 1978). In spite of the strong positive gravimetric anomaly, the Ionian Sea seems to have a thinned continental crust (MORELLI ET AL., 1977). This abnormal and localized thinning of the crust may result from its having been forced down by the overthrust of the opposed Hellenic and Calabro-Sicilian arcs, with a consequent increase of the subcrustal pressure and the rise of the Moho (BRUNN 1978-a).

Seismic reflexion diagrams do not show the exact location of the Calabrian thrust. It may be concealed by the gravity nappes of the Messina cone. Its existence, however, is supported by the occurrence of deep earthquakes and volcanism that may be followed as far as the Eolian Islands (GIESE &MORELLI, 1975; IACOBUCCI ET AL., 1977).

Recent observations by ROSSI &ZARUDZKI (1978) describe the seamounts of Cyrene and Messina as sedimentary features staying at medium depth as local remains of the general foundering of the Ionian Sea.

The southern and northeastern margins of the Tyrrhenian Sea correspond to various units of the Apennine orogene. To the north are found N-S ridges and furrows corresponding to a succession of Ligurian and Tuscanian units. They disappear towards the south on the brink of the bathyal plain between 2000 and 3000 m. The physiography is more complex offshore from the Marches and Lucania. It suggests the shearing off of units of Tuscanian or more external zones. Along the Calabrian Arc, where relative displacements were most important, the margin is narrower and rich in volcanism. North of Sicily, a succession of E-W dislocations bear the mark of the horizontal displacements of the most internal units.

Finally, the western margin, along Sardinia, is formed by N-S ridges that seem to be a southern prolongation of the internal units of NE Corsica. It is difficult, however, to locate precisely the limit between the Alpine orogene and the old basement of Corsica and Sardinia.

The emplacement of Corsica and Sardinia has been much discussed. Since the work of ARGAND (1924) it has been admitted that this block has been rotated away from its original position along the Maures Massif and the Lion Gulf. Most palaeomagnetic data seem to confirm the rotation, but some amount of translation towards the NE may have occurred. This would alter the supposed initial position (ALVAREZ, 1972; STOREVEDT & PETERSEN, 1976; WESTPHAL ET AL., 1976).

One point is certain, i.e., that the present day orientation of the basement and the emplacement of the Alpine Corsican nappes were already acquired at the beginning of Miocene times, for quite some Miocene formations extend from Corsica to Elba (ORZAG-SPERBER, 1978), allowing only a slight distension between the two islands. On the contrary, the system was still mobile at the southern end where the Numidian Flysch furrow was still active at the north of Tunisia until and during Burdigalian time. The expulsion and emplacement of these nappes took place only during Middle and Late Miocene, so that the system here only closed with the Tortonian. Since then, a rigid bridge of continental crust has existed along the axis Tunisia-Corsica-Genova. It acted like a puncheon, arching the Genova area and contributing to the extension of the Western Alps towards the SW, W, and NW. In this compression, the Corsican crust would have been thrusted under Adriatic crust of the Ligurian area, according to MORELLI ET AL. (1977).

The mechanism of the Corso-Sardinian rotation is still conjectural. It may have been a part of a mosaic taken up within a mobile zone of apenninic type. It may also, following ARGAND's (1924) idea, have been dragged along in the course of the formation or eastward accentuation of the great Apennine-Calabria-Sicily-Kabylia Arc.

The probable thrust of the Tyrrhenian area through the Calabrian-Sicilian Arc over the Ionian crust has been mentioned above. The repartition of the main apenninic and sicilian nappes may be understood if it is realized that their original area was much narrower than it is today in the transverse i.e., E-W direction while it was longer from north to south. The most internal zones travelled a long way towards

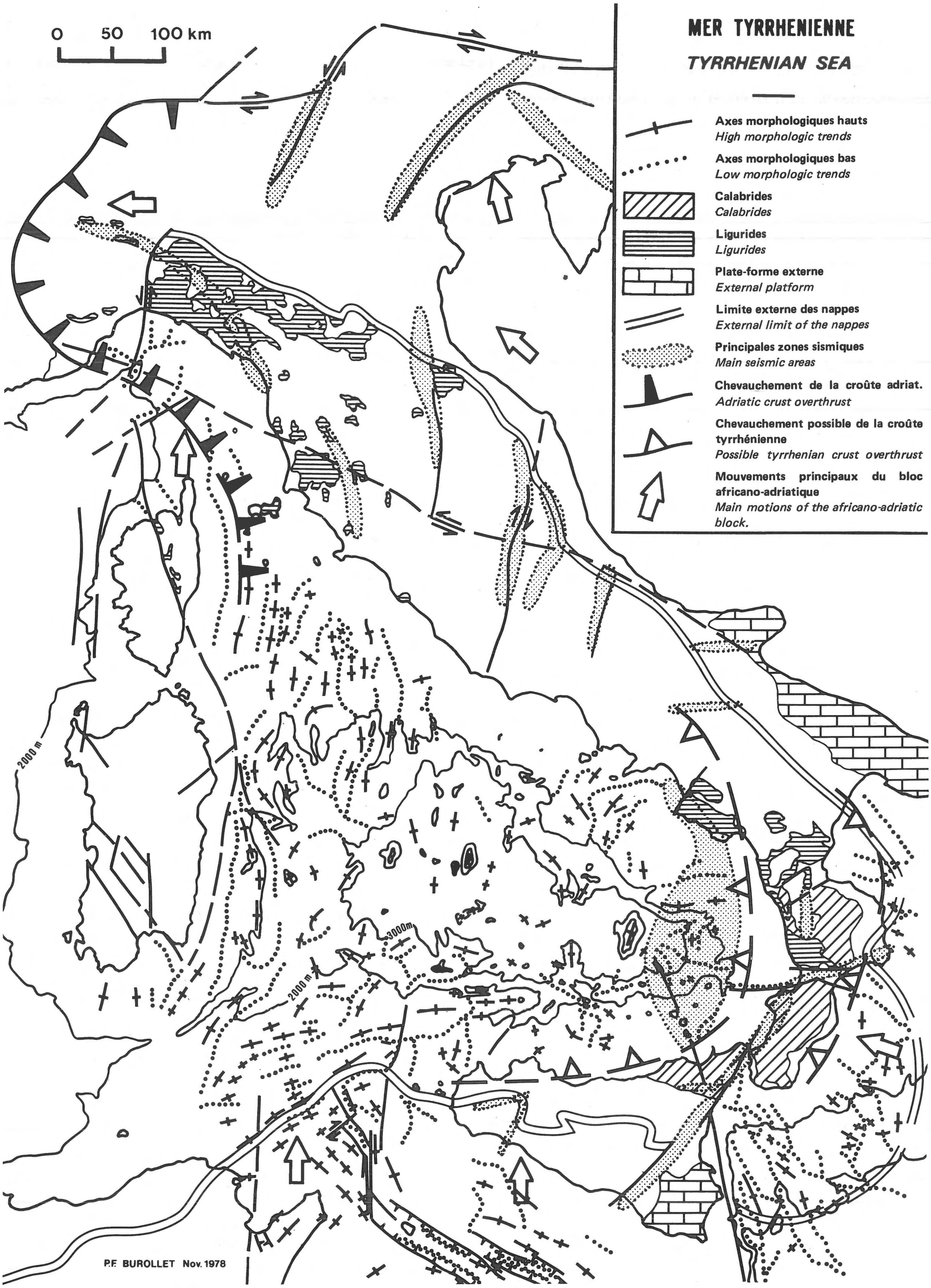

Fig. 1
Tectonic sketch of the Tyrrhenian Sea.

the Calabrian Arc and the northeast area of Sicily (GRANDJACQUET & GLANGEAUD, 1962). Next to these, the other units must have been disposed in an order similar to that of their present day succession, i.e., from W to E: Ligurids, Sicilids and 'Argille Scagliose' complex, oligo-miocene flysches tardily associated to these units (Monferrato, Reitano); further were to be found units corresponding to the Tuscany nappes and autochthonous, then to the carbonate units of the Apennines, with their associated flysch; finally the outer, para-autochthonous zone that underwent moderate displacement was immediately preceded by the carbonate platforms: Adriatic, Apulian, Sicilian, and Pelagian. Each of these units occupies a surface that is hardly smaller than it was originally and it should be possible to reconstitute each of them.

The abyssal plain represents the tearing apart of these zones following the gradual curving of the Calabro-Lucanian Arc. Intermediate crusts of the alpine type were stretched and down faulted along the margins of the basin, while in its centre they disappeared completely leaving only a thin oceanic scar covering the mantle.

To sum up, the Tyrrhenian Sea is inherited from a sheaf of Alpine ridges and furrows located between the Corso-Sardinian group to the west and the African-Adriatic platform to the south and east.

The Apennines, Calabria and the north of Sicily are made of allochthonous units, some of which have travelled a long way. They have undergone the influence of deep fractures of the African basement mainly directed N-S. Most earthquakes are lacated along these dislocations, although the deepest ones are to be found at the rear of the overthrusting Calabro-Lucanian Arc. The Tyrrhenian Sea floor owes its nature to the double effect of a transverse, E-W, extension and laceration on one hand, and of longitudinal, N-S, compression on the other. Both types of deformations are today practically blocked by the promontories. It is this compression that determined the lateral expansion of the Calabro-Lucanian Arc.

The Aegean inducted arc

The Aegean area has been the object of numerous studies and of six international colloquia. It has been claimed to be a typical sedimentary and volcanic island arc and ascribed to the subduction of a 'Tethysian ocean' under an 'Aegean plate' (MCKENZIE, 1970).

This last notion has been modified by its author (MCKENZIE, 1976). Moreover, parts of the arc are fortunately observable on land, in the Peloponnesos to the west and in the Lycian Taurids, up to the town of Isparta, to the east. In both areas, it is obvious that the arc is composed of complex nappes thrusted over continental platforms, the Ionian to the west and outer Tauric (Syrian) to the east. Recent volcanism is, moreover, far more widespread in Anatolia than along the arc. The whole system, including its two seas, is nonetheless a highly interesting feature and its study may shed some light upon the problem of folded arcs (BRUNN, 1976, 1978-b, c).

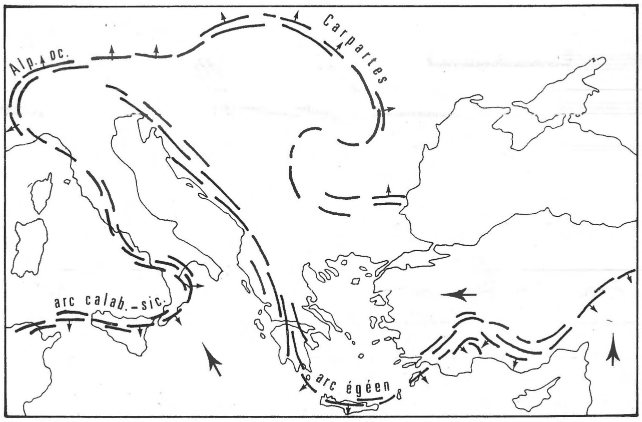

Fig. 2
The Aegean and Calabro-Sicilian arcs. Arrows indicate motion of the main blocks.

Progress of the geological knowledge of the islands has confirmed that they represent the continuation of the structures known in the Hellenides and in the Taurides. Sometimes with other names and slight differences in facies, the main hellenic zones: Ionian, Gavrovo-Tripolitza, Pindus, were followed and recognized along the outer arc, in Crete, Karpathos and Rhodes, accompanied by scattered outcrops of thrusted ophiolites (cf. works of AUBOUIN ET AL., 1976; EPTING ET AL., 1972; BONNEAU, 1973 etc.). A new and important feature for these outer zones is the occurrence of a fairly intense but variable metamorphism, both in greenschist and blueschist facies, and even of recent (Miocene) granitization in Cos (ALTHERR ET AL., 1976). Beyond the latter and the four or five volcanic islands of the inner arc, the Kykladic arc comprises mainly crystalline rocks and marbles similar to those of the Menderes massif of western Turkey and, to some extent, to those of southern Eubea. As is the case in the two last areas, the metamorphism in the islands is partly recent or, at least, rejuvenated. Still further north, the Sporades have features in common with the Vardar zone of Greece and Yugoslavia, Ohios and Mytilene with the Izmir area (BRUNN, 1978-a).

Also with respect to their evolution in time, the Aegean islands share the history of the continental ranges: most, if not all, the units involved remained undisturbed until the end of Cretaceous and were tectonized at various epochs of the Tertiary.

Having stressed the analogies showing that the Aegean area is definitely a part of the Hellenic-Tauric ranges, some significant differences and peculiarities should also be stated. Metamorphism reaching the outer zones (for it is normally well developed in the Inner-Hellenic zones) has already been mentioned. This is the case in the Peloponnesos, where parts of what was considered before as the old basement in the Taygetos, belongs to the Ionian zone and includes Lower

Oligocene (BIZON & THIEBAULT, 1973). Similarly, these outer zones, that were autochthonous or para-autochthonous in continental Greece, where they were defined, are involved in complex nappes all along the arc, from the Peloponnesos to the Lycian Taurids. In the latter area, a pile of units that had already undergone complex Palaeocene to Eocene dislocations and thrusts, were thrusted again (as shown by the presence of the Göcek tectonic window) upon the Burdigalian top layer of the Bey Daglari platform series. This autochthonous unit is comparable both to the Syrian and to the Apulian platforms. They represent the African margin and there is every reason to admit that they are in continuity and constitute the foreland of the Aegean arc and the subsided floor of the eastern Mediterranean.

Geophysical data (MORELLI ET AL., 1977) indicate here thinned continental crust. In the frontal Aegean islands, tectonic complexity is at its highest: all visible units, including equivalents of the Ionian zone, are thrusted one on top of the other in apparent disorder. They gradually recover their normal relative position from the north of the Peloponnesos into continental Greece, i.e., Apulian (pre-apulian), Ionian, Gavrovo, and Pindus zones, the latter only being systematically allochthonous. This shows that the tectonic climax and the maximum thrusting are related with the formation of the arc. In spite of these signs of highest tectonic stress, the width of the range is at its maximum across the Aegean sector where it reaches nearly 1000 km from Crete to the outer edge of the Balkan in Bulgaria (Fig. 2).

This may be compared with the 250 km wide eastern Taurids where the folding is clearly due to compression by the Arabian shield. If one adds radial vergence of the arc (S-W in the Peloponnesos, S in Crete, and SE in the Lycian Taurids), it becomes obvious that the folding and thrusting of the arc is not due to the northward movement of a 'Tethysian plate', but to an active, outward thrust over its foreland.

The clue of this peculiar disposition lies in the overall structure and dynamics of the range. The Aegean bulge results from the westward movement of Anatolia, being barred to the west by the eastward thrusting Calabro-Sicilian Arc. Because it is a secondary consequence of the main movement, the term 'inducted arc' has been proposed (BRUNN, 1976) to designate such a structure. Inducted arc tectonics are opposed to collision tectonics as exemplified by Himalaya and (more obliquely) in the Zagros and also in the eastern Taurids concave arc.

The westward movement of Anatolia is proved by the occurrence of numerous right-lateral earthquakes along the North-Anatolian fault (Fig. 2). The large crushed zone that follows the fault line shows that it has been in action for a fairly long time, actually since Early to Middle Eocene. It is related to the movement of the Arabian Wedge towards the north or the northwest, between the right-lateral inner Zagros main fault to the NE, and the East-Anatolian-Levant (Lebanon) left lateral fault to the west.

The induction of an arc imposes deep strains and deformations to the lithosphere. Neo-tectonic studies (ANGELIER, 1976; MERCIER ET AL., 1976) have shown that the arc has been mainly in the state of compression all around its rim, since the Late Miocene, while the Aegean Sea area mainly underwent distension that caused its downfaulting and its well-known late invasion by the sea. The distension is also at the origin of high heat flow (much higher than in the eastern Mediterranean) and even, according to several authors, of submarine effusions and of conditions recalling rifting and the birth of an ocean. Nearer to the arc, at the level of the Cyclades, warping of the lithosphere generated great amygdaloid anticlines. The most typical and fully observable type for these is the Menderes Massive of western Turkey, but similar structures are revealed in the islands, for instance in Naxos, where the recent mollassic sediments are folded. The Menderes massive is 150 km wide, and fairly steep on its margins. It involves the whole of the lithosphere, for its uplift induced thermal metamorphism: by relieving the mantle of the weight of the lithosphere, it caused the separation and the departure of volatiles, (water, silica, and alkalines), their rise towards the vault and through the lithosphere and crust. This process is demonstrated in the Menderes by the fact that the last levels to be folded are Late Cretaceous-Palaeocene in age, and that they have undergone metamorphism, while the unconformable Oligo-Miocene mollasse of Tavas remained untouched. The Miocene granite of Kos is also coeval to an upheaval for it is in the heart of an anticline and was eroded before receiving slightly later nappes (ALTHERR ET AL., 1976).

If this 'drawing up' of volatiles may explain the localization of thermal metamorphism and granitisation in large vaults, it may also give birth to volatile-rich acid and intermediate volcanism through a slightly different tectonic context: it may, for instance, represent the transition from the compressive state of the frontal arc to the extension prevailing in the intra-arc basin. It might also result from the crossing of an arcuated structure by radial faults or dislocations occurring slightly inside the frontal arc. These are only working hypotheses that may guide field researches around volcanoes. It is well known that no convincing explanation of volcanism through subduction has yet been proposed, especially in view of the cooling of the mantle that would be produced by the downgoing slab and its melting.

Around the arc, focal mechanisms reveal right-lateral movements to the south and thrusting in the Ionian area. This is coherent with the westward push of Anatolia, the behaviour of the arc becoming slightly more rigid. The frontal trenches rising towards the south to the Mediterranean Ridge should be compared to the mollassic furrows that surround all arcuated folded ranges. It expresses the bending of the platform under the pressure of the advancing arc, with an elastic uplift at the south.

The main interest of the inducted arc mechanism is to draw attention to the importance of lateral, oblique, or longitudinal displacements in the building of a mountain range.

The Ceram Arc

The main tectonic mechanisms involved in eastern Indonesia may be listed in the following terms notwithstanding other possible interpretations.

(1) Subduction of oceanic floors with deep trenches and a Benioff zone. The best example of this disposition lies in the southwest, where the Indian Ocean floor dips under the Sunda Shelf, which is giving birth to an outer (submerged) arc, to a 3000 to 5000 m deep trough such as the Lombok basin and to an inner volcanic arc (Java, Bali).

Equally characteristic is the Mindanao trench sector. The Philippine Sea floor should be mainly of oceanic nature, whatever its origin may be. But the Mindanao volcanism is essentially of Mio-Pliocene age and only two volcanoes are active on the west side, this suggesting change in the dip of the Benioff surface.

These two areas are, however, the only ones where the occurrence of this type of phenomena may be considered as established. The existence of subduction zones has been alleged by various authors along Palawan, south of the Sulawesi Sea, or west of Sulawesi in the Makassar Strait. There is nothing in this which is really convincing, although depths of over 5000 m in the Sulawesi Sea remain to be explained. The Sulu trough between northwest Kalimantan and Negro, may have been related to such mechanisms during fairly recent times, but the volcanism of the Sulu arc and of the western peninsula of Mindanao has been inactive since the Late Miocene. On the other hand, the nature of the Sulu trough floor is still unknown (Fig. 3).

(2) The second mechanism is the subduction of a continental zone or crust under an arc or, alternatively, the overthrust of the latter above the former. In the course of this process, melanges and secondary nappes are pushed forward in front of the arc, as is the case in Timor and to the east of Ceram. An outer sedimentary arc is lined by an inner volcanic arc that is still very active from Flores to the south of Ceram. A similar phenomenon must have taken place during Miocene to the east of Sulawesi, with the collision of the Puleng, Bandai and Sula block, the extrusion of ophiolites and associated formations, and the volcanism that occurred in the NE and NW arms of Sulawesi, as well as in the Toyan archipelago. The only active volcano is now Unau-Unau. It represents either the survival of the initial process, but it may also express the existence of a major dislocation. The absence of deep earthquakes is disturbing. A similar mechanism has possibly been active east of Almahera where the Waigeo block must have played the same role as the Puleng and Bangai block in respect to Sulawesi. Not enough is known about this area to allow more precise hypotheses. Because evidence is not compelling, various models have been put forward. CAREY (1975), for instance, sees in arcs and trenches rather the result of distension than of convergence; the authors are inclined to stress the role of the active deformation of arcs and this point will be developed farther on.

(3) Yet another disposition may be defined as the subduction of the crust of undetermined nature under an arc. We shall assign to this type the eastern end of the northwestern arm of Sulawesi, the Talaud ridge representing the non-volcanic arc with the strong negative Bouguer anomaly, while the Gorontalo basin would represent the intermediate trench. This interpretation is confirmed not only by volcanism, but also by the depth of earthquakes that are distributed along the plane inclined from 0 km to the southeast to 600 km under the Sulawesi Sea. On the other hand, the eastern side of the Talaud Basin has been discussed by various authors but precise information is still lacking. The symmetry of the two volcanic arcs-Almahera to the east, Sulawesi arm to the west on both sides of a negative anomaly is, of course, very striking. It is tempting to assume the existence here of a convergence axis, drastically reduced by collision, only the deepest parts of the Benioff planes being left. On the other hand, the resemblance between Almahera and Sulawesi cannot be overlooked. It suggests a westward subduction of a subcontinental shelf located north of the Sorong fault.

It should be noted, however, that the eastern arms of Almahera do not present a negative anomaly as do those of Sulawesi.

(4) Transcurrent faults play an important part in the whole area. Although complex, their distribution follows some very regular trends. Two main directions seem to predominate, both being mostly left-lateral. One strikes NNW or NW: Sulawesi, Sumba, centre of the Banda Sea. The NW arm of Sulawesi is crossed by a NW striking dislocation that looks as if it were right-lateral, while it is left-lateral in depth, at the level of the subduction zone that exists to the east. The superficial appearance of right-lateral movement is due to the push of the southward spreading volcanic arc.

Another main direction is E-W and these dislocations are also usually left-lateral, such as the Sorong or the south Ceram faults. They may, however, be locally right-lateral if a particular compartment is left behind by the general westward displacement: such is the case of the Misol and Bintuni faults, south of the west end of Irian Jaya.

These major transcurrent faults express the reaction of fragile continental blocks to the north-northwestward movement of Australia. This should include an east-west trend due to the movement of the north of New Guinea and this in turn may be in relation with fundamental displacements of the Philippine Sea floor or even of the Pacific Ocean. In the Makassar Strait, the main fractures separating zones of different depths strike to the NW or the NNE. We would be inclined to consider that these directions do not coincide with that of the deep dip-strike movements, but that they represent superficial reactions to deep left-lateral NNW trans-

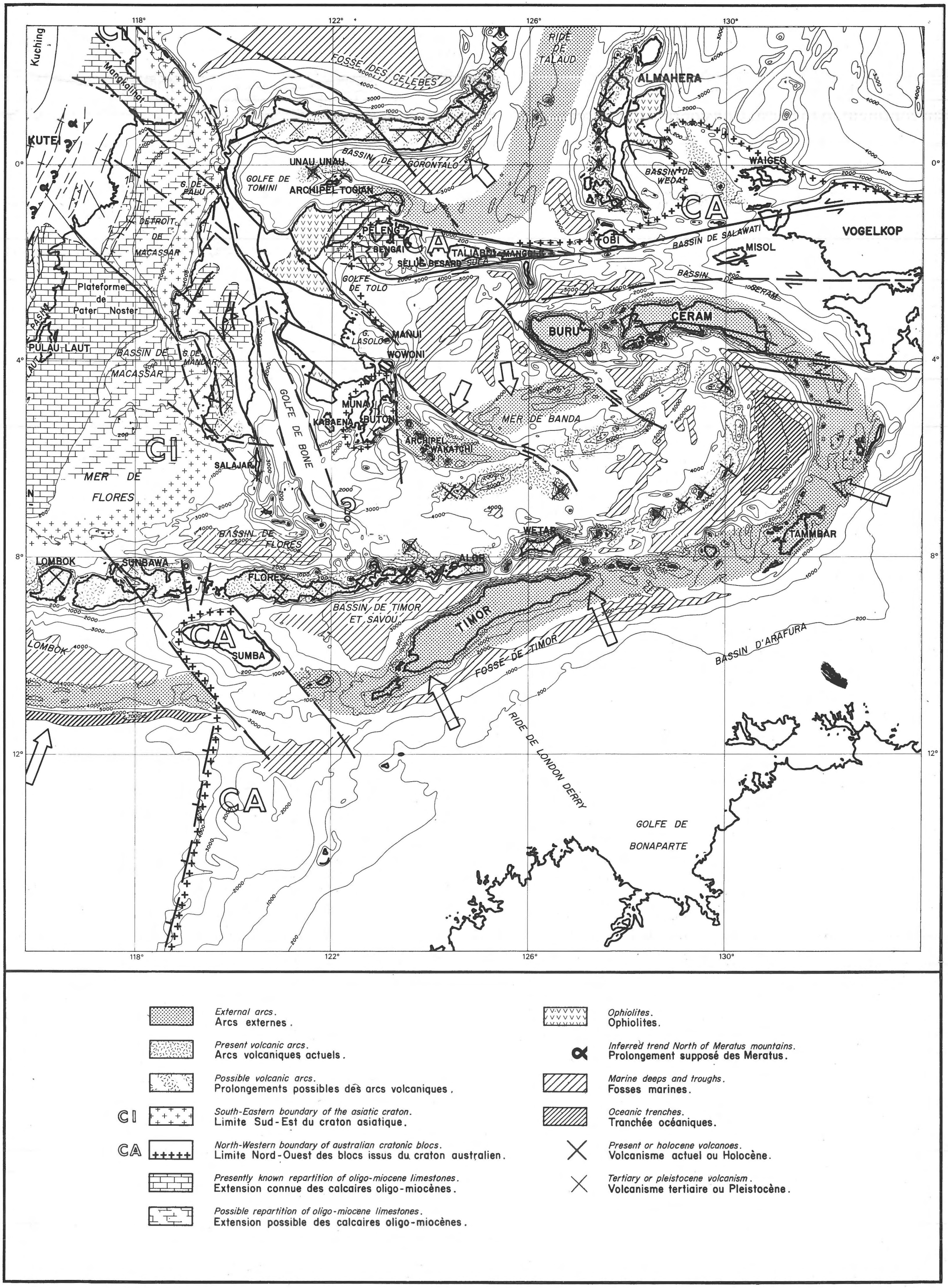

Fig. 3
Tectonic sketch of Eastern Indonesia. Arrows indicate motion of the Australian craton pieces and of ocean floors (Indian Ocean and Gorontalo Basin).

current faults and they limit downfaulted 'rhombochasms'.

A great N-S dislocation separates, south of Sumba, the oceanic area to the west from the prolongation of the Australian continent to the east. Considering the offset of the trenches, it seems to have a right-lateral effect in depth, but a left-lateral counter-effect reaches the frontal arc. Sumba should represent a floating fragment that escaped any strong tectonization, and was inherited from an uplifting of the eastern compartment of the great dislocation bordering the Indian Ocean.

In sum, the Sumba and Flores area are still fairly mysterious, being at the crossroads of various components and forces. Many features remain to be explained: the absence of a negative gravity anomaly along Sumba, the existence of a deep trench (over 5000 m) north of Flores, although it might be compared with the trench that occupies the heart of the Ceram Arc. The Flores area presents, however, no sign of similar stretching and tearing.

The interpretation of the Banda Sea itself is not obvious. As a working hypothesis we would suggest a longitudinal extension similar to that of the Tyrrhenian Sea at the rear of the Calabrian Arc. Somewhat in the same way lithospheric downthrusting must have taken place to the south owing to the collision of the Sula and Peleng raft. Between Buru and SE Sulawesi, the deep basin would correspond to a southward downthrusted segment which is separated from Buru by the main left-lateral shear-fault, with a large offset of the external and volcanic arcs remaining submerged (Fig. 4).

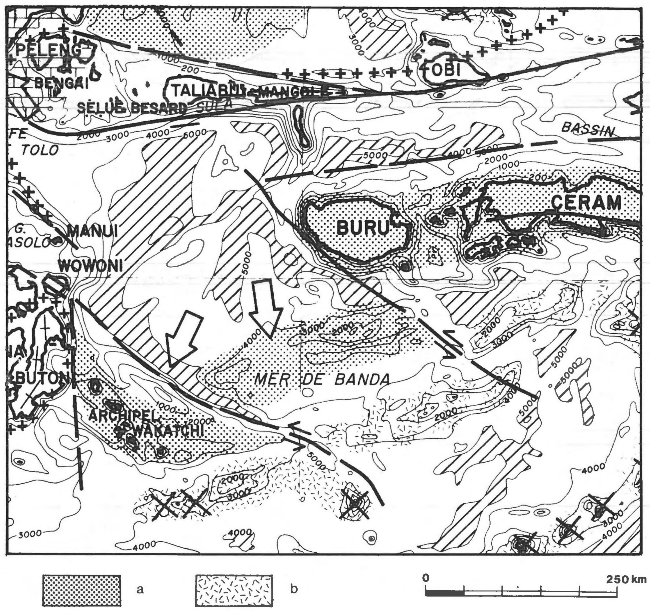

Fig. 4
Inferred role of left lateral shear faults west of the Banda Sea.
a : external arc;
b : volcanic arc.

CONCLUSIONS

The generation of island arcs and of orogenes

In the three areas reviewed the context in which arcs were generated was either strictly continental (although largely submarine) or partly oceanic (the best example being the great Indonesian Arc). Even in the latter, however, the arcuate zone is very little disturbed, after it crossed the limit, west of Sumba, between the Indian Ocean and the prolongation of the Australian continent. Whatever the case, the arc phenomenon retains its main features with more or less regularity: its shape, of course, fairly often the double line, sedimentary and volcanic, separated here and there by trenches, the intra-arc basin, sometimes with a secondary crust of oceanic type, and finally, a Benioff zone described by the foci of earthquakes, if the structure is still active. This is completed or replaced by evidence of thrusting and radial spreading when the structure is older.

Thrusting implies crustal shortening and the Benioff zones, when they exist, show that this shortening may reach great depths. In the case of arcs, however, thrusting of the rim is often combined with, or to a certain extent compensated by, stretching of the intra-arc basin. It is the whole of the deformation that should, therefore, be considered.

The Aegean area offers a fairly simple example of the induction of an arc through a locally longitudinal compression determining a bulge in the range and a radial spreading compensated by extension in the intra-arc basin. In the Tyrrhenian intra-arc sea, transverse extension is accompanied by N-S compression related to the partial closing of the arc. In the Banda Sea, longitudinal W-E stretching is associated with a transverse N-S constriction, related to the northward or the northwestward advance of Australia.

The role of the Australian drift in the formation of the Indonesian arcs has been stressed by many authors, since Wegener himself pointed it out. The frame may, however, be enlarged, both in time and space.

In time, the tectonic interplay of ridges and basins, is at least older than known disconformable Cretaceous formations. This shows that this area has been for a long time characterized by the mobility and the fragility that is still exhibited today; that crustal shortening has consistently taken place in the whole area and has not been restricted to subduction zones facing the Pacific or Indian Oceans. The question, then, is that of the origin of these particular characteristics.

In space, if Indonesia and the western Pacific are considered as a whole, it becomes clear that not only the movement of Australia is involved, but also the great north-south shortening implied by the growth of the Indian Ocean, the Himalayan thrust, the closing of the Tethys, and relative shortening of the Asian continent itself. The warping and dislocation of the Indonesian and western Pacific areas appear then as the inevitable consequence of its being caught between these moving and shortening parts of the lithosphere to the west and the central Pacific to the east. The effect of this relative longitudinal movement is necessarily the induction, through warping, of uplifted arcs and subsiding basins of more or less amygdaloid shape, with magmatic consequences somewhat similar to that observed in the Aegean arc and basin: intermediate to acid magmatism in uplifted structures, submarine basic outpourings creating new crusts of oceanic type in the stretched basins. This elongated area having thus been weakened by these dislocations, could take in the excess surface generated by expanding oceans; it was not a subduction, but a *crustal resorption area.*

The same fragility and mobility characterize orogenes, whatever was the nature of their crust, whether continental or oceanic, with respect to the adjoining cratons. This suggests they were initially dislocated and weakened by being warped between cratons or parts of cratons moving in opposed, but parallel directions. Traces of the initial dislocations may be found in coarse breccias such as the 'sparagmite' of the Caledonian Eocambrian or in the exotic blocks that are often strewn here and there in Alpine Triassic. On the margins, the emersion of arcs, isolated and originated confined subsiding basins, such as the Cambrian aluniferous formation of the Oslo area or the thick Triassic gypsum of the western Alps or of the Adriatico-Ionian zones, respectively on both margins of the alpine orogen. In the more severely dislocated inner zones, repeated deformations are marked by volcanism and by detrital and pyroclastic sedimentation in subsiding basins, a picture similar to that of the Ordovician geosyncline depicted by Marshall Kay. In the most stretched basins, submarine effusions of mantle magma gave birth to new and local 'oceanic crusts' that later became strings of ophiolitic massives. Early tectonics were developed in this marine context, independently from cratonic collisions, merely through the deformation of existing arcs. An emerged range was only realized when cratons converged and collided. Existing arcs were more or less closed and ejected upon platform margins; late inducted arcs, such as the Aegean, were formed. The maintained obliquity of general strains found its expression into great transcurrent longitudinal faults.

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