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Meso-Cainozoic palaeogeography of the Middle East: constraints from the Iranian sutures

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ABSTRACT. — Ophiolitic sutures in Iran define a block here called Central Iran and a Lut block, which are also separated by sutures from Eurasia and from the Afghanistan-Pakistan blocks. These blocks were parts of Gondwana until the Early Kimmerian dislocation of its northeastern margin. Available evidence concerning the sutures are as follows. The ophiolites show geochemical characteristics either of island arc (Zagros, Sabzevar, Nain, Baft) or mid-ocean ridge (Baluchestan). Both effusive magmatism and emplacement have been radiometrically or biostratigraphically dated as from latest Cretaceous to Eocene. From these data, tentative palaeogeographical sketches have been prepared, which show the Gondwanian fragments drift toward Eurasia and their accretion to it, between the Triassic-Jurassic boundary when Neotethys opened, through early Late Cretaceous, that is just before most ophiolite obductions were induced, either by arc-continent or subduction zone-continent collision, up to Late Oligocene when continent-continent collision had occurred, or was about to occur and when further pushing stress from Arabia and India was accommodated in the Middle East blocks by wrench-faulting and crustal shortening. The case of Iranian sutures shows that continent-continent collision may occur a long time after ophiolite obduction, without leaving any ophiolitic signature.

RÉSUMÉ. — Les sutures ophiolitiques iraniennes définissent un bloc appelé ici Iran central et un bloc du Lut, unités que des sutures séparent aussi de l'Eurasie et des blocs afgho-pakistanais. Ces deux blocs formaient partie de Gondwana jusqu'à la dislocation éocimmérienne de sa marge nord-orientale. Les données disponibles concernant ces sutures sont les suivantes. Les caractères géochimiques des ophiolites sont soit ceux d'arc insulaire (Zagros, Sabzevar, Nain, Baft), soit ceux de ride médio-océanique (Baloutchistan). Les âges radiométriques ou biostratigraphiques du magmatisme effusif et de la mise en place vont de la fin du Crétacé à l'Eocène. Des schémas paléogéographiques fondés sur ces données montrent, à trois époques, la dérive des fragments gondwaniens vers l'Eurasie et leur rattachement à ce supercontinent : à la limite Trias-Jurassique lorsque s'ouvrait la Néotéthys; au début du Crétacé supérieur, c'est-à-dire juste avant que n'aient lieu la plupart des obductions d'ophiolite par collision entre arc et continent ou entre zone de subduction et continent; et à l'Oligocène supérieur, lorsque la collision intercontinentale avait eu lieu ou était sur le point de se produire et quand les blocs du Moyen-Orient réagissaient par des fractures en décrochement et des raccourcissements crustaux à la poussée qui continuait à s'exercer de la part de l'Arabie et de l'Inde. Les sutures iraniennes sont un exemple montrant que la collision intercontinentale peut avoir lieu sans laisser de témoin ophiolitique longtemps après l'obduction des ophiolites.

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INTRODUCTION

In his structural correlation of the Alpine ranges between Iran and Central Asia, STÖCKLIN (1977) distinguished :

1) A southern, Gondwanian, domain comprising the Zagros fold belt in front of Arabia and the Himalaya marginal fold belts in front of India;
2) A ramified axial ophiolitic belt, representing remnants of Neotethys, which during the Mesozoic separated the Gondwanian fragments from both Arabia and India;
3) A central domain, formed by continental crust fragments that during early Mesozoic were dissociated from Gondwana and attached to Eurasia; these continental fragments were subjected to Kimmerian and Eoalpine tectonizations;
4) A northern domain, deformed during the Hercynian and Kimmerian orogenies, including probable remnants of Paleotethys and constituting the Eurasian margin.

This paper is concerned with Stöcklin's domains 2 and 3. Its purpose is to show the constraints which recent geochemical and geochronological data from Iranian ophiolitic sutures (DELALOYE and DESMONS, 1980; DESMONS, 1981; DESMONS and BECCALUVA, in press) impose on palaeogeographical reconstructions of the northeastern margin of Gondwana. A brief review of the data on the Iranian sutures (domain 2) bounding the continental fragments (domain 3) will be followed by a discussion of tentative palaeogeographical reconstructions, emphasizing both constraints and hypotheses.

The reference list has been kept as short as possible; further references can be found in the cited papers.

BLOCKS, MARGINS AND SUTURES

From ophiolite and melange occurences, two continental blocks may be individualized in Iran between Arabia and Eurasia : in the west a block here called Central Iran and in the east the Lut block (fig. 1). Both show a crystalline basement consolidated from Precambrian times, with a lower Palaeozoic sedimentary evolution similar to Afro-Arabia (STÖCKLIN, 1968), later imprinted by Hercynian epeirogenic deformation. In contrast to main Gondwana, Central Iran, and to a lesser extent the Lut, were affected by the Early Kimmerian orogeny. Plant fossils with Eurasian affinities, contained in Lower Jurassic formations (STÖCKLIN, 1974; HALLAM, 1981), are evidence of Central Iran being connected to Eurasia at that epoch, a fact also supported by a few palaeomagnetic data (WENSINK and VAREKAMP, 1980, with previous references). A similar conclusion has been attained concerning the northern part of Afghanistan (HALLAM, 1981, with previous references).

Central Iran.

The southwestern margin of Central Iran is formed by the Sanandaj-Sirjan range, a unit that shows the effects of Early Kimmerian deformation, metamorphism and magmatism. In the Zagros thrust belt ophiolites and melange constitute the upper nappes, thrust southwestward onto the sediments of the Arabian margin. The late Mesozoic oceanic gap was located between the Sanandaj-Sirjan range and these Arabian sediments. K-Ar radiometric whole rock ages of 81 and 86 + 8 Ma (Cenomanian-Santonian) have been interpreted as probably close to the time of effusive ophiolitic magmatism (DELALOYE and DESMONS, 1980). Other data, suggesting Albian-Cenomanian or Cenomanian-Turonian ages, have been obtained on metamorphic minerals from exotic rocks in melange, from Sanandaj-Sirjan metamorphics, and from basal amphibolite (ADIB, 1978; HAYNES and REYNOLDS, 1980; PAMIĆ and ADIB, 1982). The geochemical characteristics of the Zagros ophiolitic sequences (DESMONS and BECCALUVA, in press, with previous references) indicate typical island-arc affinity. Ophiolite emplacement on the Arabian margin, as well as thrusting of the other Zagros nappe units, have been biostratigraphically dated as earlier than upper Maastrichtian (STÖCKLIN, 1974 : RICOU *et al.*, 1977). The Arabian margin itself, i.e. the Zagros fold belt, was not folded before Plio-Pleistocene times. Thus, a latest Cretaceous arc-continent collision (Zagros ophiolites-Arabia) largely predated a late Cainozoic continent-continent collision (Central Iran-Arabia). This is a fact that allows inferences to be made as to palaeogeography and palaeotectonics.

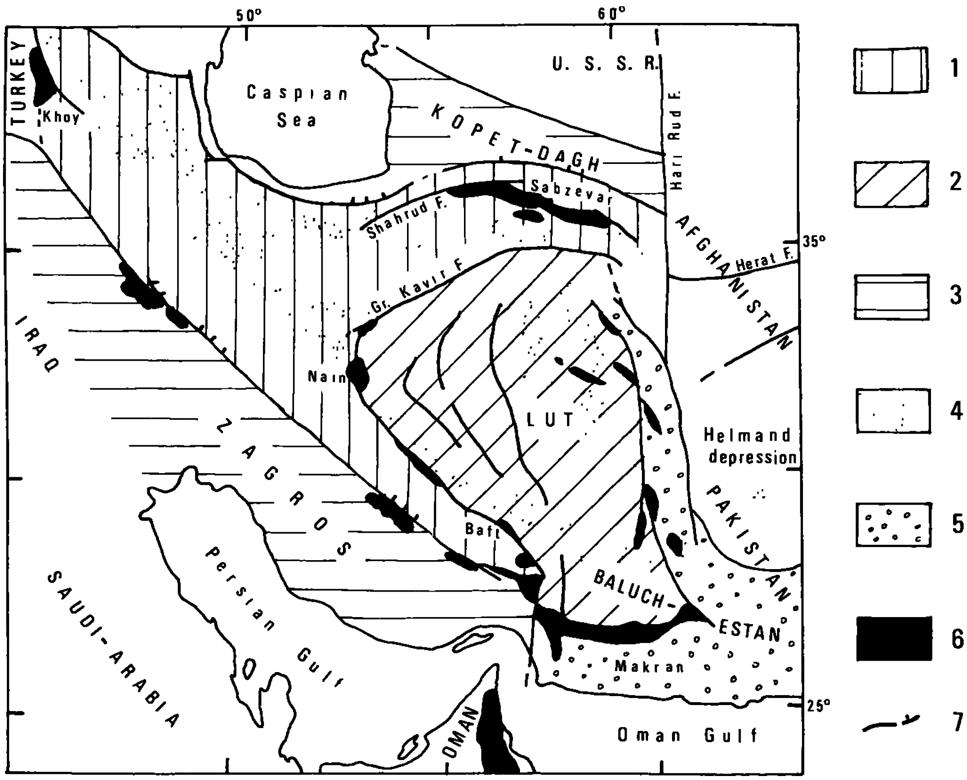

FIG. 1. – Sketch map of Iran showing continental blocks, sutures and major faults. 1, Central Iran block; 2, Lut block (the Central Iran and Lut boundaries are uncertain in NE Iran, see text); 3, Zagros fold belt (Arabian margin) and Kopet Dagh fold belt; 4, Cainozoic volcanics; 5, Late Cretaceous-Eocene flysch of the East Iranian ranges and Cainozoic sediments of the Makran wedge; 6, post-Paleozoic ophiolite and melange, undifferentiated; 7, Major faults (where recumbent, with barbs on the upper side).

The calc-alkaline to alkaline volcanics, mainly Cainozoic in age, that are widely developed in Central Iran in a trend parallel to the Zagros, may be interpreted as related to the Tertiary northeast-dipping subduction zone (not to the Late Cretaceous one).

In the Esfandagheh area, where the Zagros trend comes into contact wich the Makran trend across the Oman fault zone, the silica-saturated character of the lavas occurring in melange and of the close-by exposed layered complex indicates an island-arc affinity for these ophiolitic exposures, also considered as emplaced in Late Cretaceous times.

The Zagros ophiolitic suture may be followed into Oman (in the Semail ophiolitic nappe), its trend being dextrally displaced along the Oman fault zone. Both Zagros and Semail ophiolites lie on the Arabian margin and the sedimentological-palaeontological characters of the associated nappes are similar. Effusive magmatism in the Semail ophiolite has been dated as about 95 Ma (Cenomanian) or older, the slicing off of ocean crust (hornblende in the basal amphibolites) as Cenomanian-Turonian (90 Ma) and the emplacement is thought to have occurred between Coniacian and early Maastrichtian (MCCULLOCH *et al.*, 1980; COLEMAN, 1981, with other references). There is no common agreement (COLEMAN, 1981; PEARCE *et al.*, 1981; SMEWING, 1981) about the geochemical affinities of the ophiolites, to ridge-generated or island-arc crust, indicating either a composite ophiolitic nappe, or an arc-back arc complex origin of a single ophiolite nappe.

To the northwest, Central Iran is bounded by the poorly studied Khoy ophiolitic occurrence, and is separated from the Anatolian plate by the Cretaceous ophiolites of the Bitlis suture zone. SENGÖR and YILMAZ (1981) have recently exposed the Tethyan evolution of Turkey, which bears many similarities in style with the Middle East.

To north, the boundaries of Central Iran may be found in the Lesser Caucasus, where the suturing was completed by the end of Paleogene times (KNIPPER and KHAIN, 1980) and north of the Alborz range, along the southern shore of the Caspian Sea (the South-Caspian depression has been interpreted by many authors as a remnant of Paleotethys, indicating incomplete Kimmerian oceanic closure; STÖCKLIN, 1974). Farther east the boundary is obscure. One possible location of the boundary might be found at the southern foot of the poorly known Kopet Dagh range. In favor of this position are the eastern continuity of Alborz Jurassic formations and a small pre-Jurassic (Paleozoic ?) basic-ultrabasic exposure near Mashad, which in its structural position is reminiscent of the Rasht occurrence in western Alborz, the other pre-Jurassic ophiolitic exposure in northern Iran (STÖCKLIN, 1974). Both may be considered as likely remnants of Paleotethys. The Sabzevar ophiolite belt, exposed south of the Shahrud-Mashad fault, is considered as emplaced in latest Cretaceous-lower Paleocene (LENSCH, 1980, with previous references). From the geochemical standpoint the Sabzevar ophiolite shows island arc affinities (DESMONS and BECCALUVA, in press). This ophiolitic belt attests to a Mesozoic suture, which together with other ophiolite and melange exposures in northern Lut, makes it difficult to unravel the relationships at the eastern Central Iran-northern Lut boundary (see following paragraphs). To suggest an additional block between Central Iran and Lut seems, at present, to belong to far-fetched imagination. Eocene to Holocene volcanics, which in the Sabzevar area are less alkaline than in southwestern Central Iran (SPIES and LENSCH, 1980), are exposed parallel to the northern margin of Central Iran, merging in Azerbaijan (NW Iran) with the volcanic lineament parallel to the Zagros.

Lut block

The Lut is a composite block, including a well-delimited eastern body, the Lut block in the commonly accepted use of the term, and a western part made up of fault-bounded elongate structural units. Post-Middle Triassic formations in the eastern Lut show slighter deformation effects than in Central Iran (STÖCKLIN *et al.*, 1972). Its northern part is hatched by several ophiolite-bearing melange and/or Upper Cretaceous-Eocene flysch exposures that merge eastward into the East Iranian ranges. Intense crushing that generated melange (DESMONS, 1981, with previous references) and recent faulting have reactivated the sutures and obliterated possible older, low-angle structures, the vergence of which in most cases is only suggested by palaeotectonic considerations.

The northern boundary of the Lut may not be constituted by the Great Kavir-Doruneh fault, a feature extending nearly 600 km, but which is a subrecent fracture and shows only limited ophiolite or melange exposure. The hypothesis that the Sabzevar ophiolite belt represents the northern Lut suture has been mentioned above.

To the east, ophiolites and melange form narrow, fault-bounded slices, that separate the Lut block from the East Iranian ranges, where Upper Cretaceous to Eocene flysch units have been folded during the Alpine orogeny. Radiometric measurements in northern Baluchestan (DELALOYE and DESMONS, 1980) point to a possible Albian-Cenomanian age (about 92 Ma) of ophiolitic, effusive magmatism, while the emplacement has been stratigraphically dated as older than Eocene. The effusive, ophiolitic rocks show geochemical characters similar to typical mid-ocean ridge basalts (DESMONS and BECCALUVA, in press).

In southern Baluchestan an ophiolite and melange-bearing suture is situated north of the Cainozoic Makran accreted wedge (JACOB and QUITTMEYER, 1979, with previous references). Effusive, ophiolitic magmatism is not younger than Campanian (DELALOYE and DESMONS, 1980). Metamorphic minerals of high-pressure facies in ophiolitic rocks and of amphibolite facies in exotic rocks, both rock type occurring in melange, have been dated as Campanian. Ophiolite emplacement therefore occurred at some time between Campanian and the deposition of the lower Makran sediments (Paleogene-Eocene). The ophiolitic sequence shows geochemical characteristics of oceanic basalts of transitional type (DESMONS and BECCALUVA, in press).

The western boundary of the Lut block may be found in the ultrabasic-basic associations and melange occurrences of Nain, Baft and other localities. The ultramafic-mafic associations do not form complete ophiolitic sequences, but the abundant, tectonic harzburgites suggest a true suture. An island-arc origin may be considered as possible, as the associated lavas show intermediate or silica-saturated chemical composition. The age of ophiolite emplacement is poorly documented. The melange contains rocks as young as Lower Eocene, but it may have been reactivated.

Afghanistan and Pakistan.

Ophiolites emplaced before the Middle Eocene are found north of the Pakistani Makran (ASRARULLAH *et al.*, 1979), continuing the Iranian south-Baluchestan suture. To the east, ophiolites and melange occur along the Chaman fault, separating the Afghanistan-Pakistan blocks from India (GANSSER, 1980, with previous references). Together with various ophiolite belts within Afghanistan, which are considered as emplaced in Late Jurassic-Early Cretaceous (along the Panjao suture which separated a northern, Turkman or Farah, block from a southern, Helmand or Central Afghanistan, block), or in Late Cretaceous-Early Eocene, these occurrences show that the Afghanistan-Pakistan block itself results from successive accretion of several blocks to Eurasia (DE LAPPARENT, 1972; BOULIN, 1981; TAPPONNIER *et al.*, 1981; with previous references). The ophiolite emplacement in most cases is thought to be directed towards India.

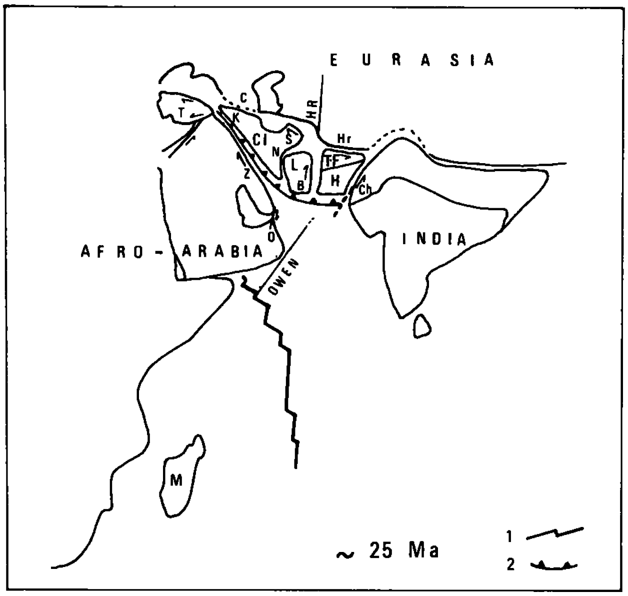

FIG FIG. 2. – Palaeogeographical sketch of the Middle East and the western part of the Indian Ocean at about 25 Ma (Late Oligocene). Explanations in text. B, Baluchestan; C, Caucasus; Ch, Chaman fracture zone; CI, Central Iran; H, Helmand block; HR, Hari Rud fault zone; Hr, Herat fault zone; K, Khoy; L, Lut Block; M, Madagascar; N, Nain and Baft; O, Oman; S, Sabzevar; T, Taurids; T-F, Turkman-Farah block; Z, Zagros; 1, ridge and transform; 2, subduction zone.

TENTATIVE PALAEOGEOGRAPHICAL RECONSTRUCTIONS

With the premise that plate tectonics were active from Permo-Triassic times in Tethys, three tentative palaeogeographical reconstructions are proposed, proceeding upward in time from the Late Oligocene through early Cretaceous times to the Jurassic-Triassic boundary, that is after progressive removal of plate motions and orogenic events from the present configuration. These sketches are intended to show which constraints are imposed by the data reviewed above. They do not propose unique solutions, but emphasize how many hypothetical fields do remain open to investigation.

Palaeomagnetic data on Iran and Afghanistan are few (see KLOOTWIJK, 1979; POWELL, 1979; WENSINK and VAREKAMP, 1980; with previous references; also CONRAD *et al.*, 1981; SBORSHCHIKOV *et al.*, 1981). These data support a drifting of these continental blocks away from Gondwana since (?Permian)-Triassic times. An anticlockwise rotation of 90° since Palaeozoic has been suggested for both Central Iran and Lut. Such a sinistral rotation appears to have affected most, if not all, Gondwanian fragments between the time of their fragmentation from Gondwana and their welding to Eurasia. It is the reflection of the similar, though smoother, movement of Afro-Arabia itself.

At about 25 Ma, Late Oligocene (fig. 2).

In Late Oligocene times, both Central Iran and the composite Afghanistan-Pakistan block belonged to Eurasia, although both blocks have since been displaced along reactived strike-slip faults (WELLMAN, 1965) such as the Herat fault zone and its possible westward continuation, the Shahrud-Mashad fault. A great part of the anticlockwise rotation assumed for the continental fragments is shown in the figure as already realized. The general movement of Central Iran during the Neogene seems to have been that of a rotating wedge pushed against Eurasia by the northward rifting and sinistral rotation of Arabia from Africa. The motion of the Lut, attested by the fault pattern around it (see the structural map of STÖCKLIN and NABAVI, 1973, and the seismotectonic map of BERBERIAN, 1976), has been directed toward the north and northwest and induced by both sea-floor spreading in the Oman Gulf and the pushing of India through the Afghanistan-Pakistan block squeezed westward. The direction of current maximum shortening in whole Iran is toward the northeast (BERBERIAN, 1976), reflecting predominant pushing from Arabia.

The Pliocene age of the earliest folds in the Zagros fold belt and in the Kopet Dagh range shows that continent-continent collisions, between Arabia and Central Iran and between Eurasia and Central Iran, were about to occur in Late Oligocene times, when crustal shortening had begun along the Eurasia-India suture zone. Thus, disappearance of oceanic crust through subduction is shown as about to stop between Arabia and Central Iran. Cainozoic subduction south of the Lut is attested by the southern Lut volcanics. The subduction zone later jumped southward to its present position in the northern part of the Oman Gulf.

As the Red Sea rift did not open widely before the Miocene, Arabia is shown welded to Africa and its Neogene-Pleistocene rotation has been subtracted from its present position. The extent of Greater India is shown according to POWELL (1979) and VEEVERS *et al.* (1980) and part of the sinistral rotation (of approximately 20°), that affected India since its collision with Eurasia, has been considered as realized. In fig. 2, as well as in both the following figures, the relationships in both the Levant and Turkey areas have been neglected as being beyond the scope of this paper.

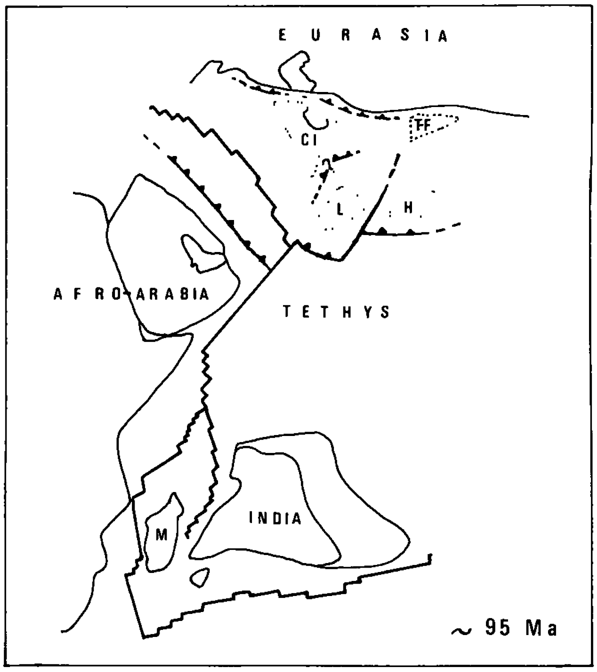

FIG. 3. – Palaeogeographical sketch of the Tethys northeast of Gondwana at about 95 Ma (early Late Cretaceous). Explanations in text. Abbreviations and symbols : see fig. 2.

At about 95 Ma, Cenomanian (fig. 3).

In figs. 3 and 4 the boundaries of the continental fragments are shown as dotted lines in order to take into account : 1) their being at many epochs below sea-level, thus forming continental plateaus, such as those currently in the Indian Ocean, the northern Mascarene, Kerguelen and Broken Plateaus, which are established on continental crust (LAUGHTON *et al.*, 1973), and 2) possible crustal shortening of the continental fragments through marginal thrusting or within-plate deformation.

In order to obtain a picture of early Late Cretaceous palaeogeography one has to remove the effects of both the Alpine proper, early Tertiary, and the Eoalpine, Late Cretaceous-Paleocene, orogenies (DESMONS, 1980) from the Late Oligocene reconstruction. The Early Kimmerian (Late Triassic), as well as the Late Kimmerian (Early Cretaceous) events, the significance of which in a plate tectonics framework is not yet entirely understood, had already left their imprints.

Palaeontological evidence indicates that both Central Iran and northern Afghanistan (the Turkman or Farah block) were related to Eurasia since Early Jurassic, that is from Early Kimmerian time. Oceanic crust of Paleotethys had probably been resorbed along a subduction zone running along Eurasia (dashed in the figure).

In the early Late Cretaceous, ophiolites were not yet emplaced on the Arabian margin as far as the Zagros-Oman suture is concerned. Ophiolite emplacement in a general way occurred on Gondwana or Gondwanian fragments, that is away from Eurasia, except along the Makran boundary of the Lut. Here, ophiolites which were derived from either back-arc basin or typical oceanic lithosphere, must have been obducted onto the Lut margin. The oceanic crust in the present-day Gulf of Oman was generated at about the same time (HUTCHINSON *et al.*, 1981).

In the Tethys between Arabia and Central Iran, an intra-oceanic volcanic arc was developed, which in latest Cretaceous times collided with Arabia, generating the Zagros ophiolitic sequences. Oceanic crust

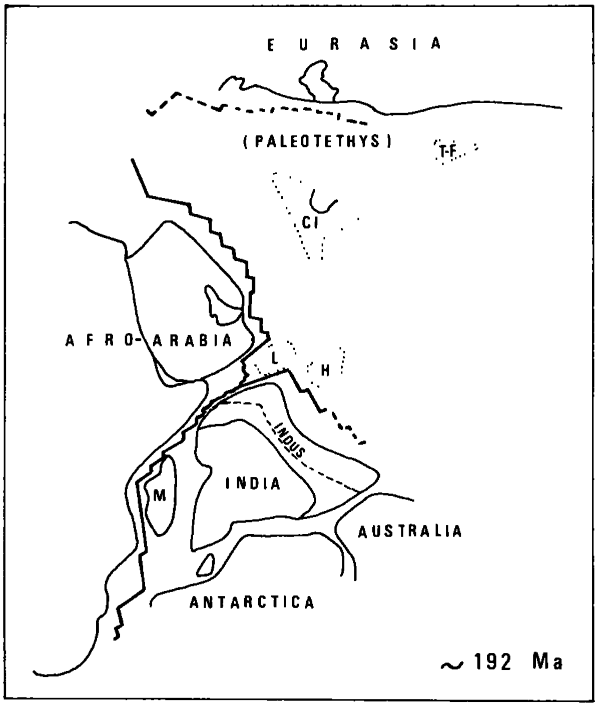

FIG. 4. – Palaeogeographical sketch of northeastern Gondwana at about 192 Ma (Triassic-Jurassic boundary). Explanations in text. Abbreviations and symbols : see fig. 2.

of Neotethys, where spreading started during the Permo-Triassic, separated this arc from Central Iran which was already accreted to Eurasia. This oceanic crust may be supposed to have been resorbed under the Central Iran margin, after the Late Cretaceous collision of the island arc with Arabia, and the Cainozoic volcanics extensively exposed parallel to this margin may be related to this latest Cretaceous-Paleogene subduction zone. As discussed above, the relationship of the Sabzevar ophiolitic belt to a specific continental margin is not unequivocally determined. The late Mesozoic configuration in this area may have been rather complicated and the configuration tentatively sketched in fig. 3 will most probably need revision.

Between Central Iran and Lut, an island arc probably existed, from which the Nain and Baft occurrences were derived. At the Makran margin of the Lut block, oceanic crust was generated, possibly in a back-arc basin environment (the geochemical characteristics are of transitional MORB). Similarly, the Cretaceous volcanic arc, individualized north of the Pakistani Makran by ARTHURTON *et al.* (1979), would also support the idea of a pre-Maastrichtian subduction zone dipping under the Afghanistan-Pakistan blocks.

Between the Lut and Afghanistan there was, in early Late Cretaceous times, typical oceanic crust, remnants of which are found in the north-Baluchestan ophiolitic sequences along the East Iranian ranges. How wide the oceanic gap may have been, that separated these blocks, is not yet determined. It may be puzzling to note the fact that typical oceanic crust is found between Lut and Afghanistan, where only a side-branch of Tethys seems to have existed, and not along presumably wide oceanic tracts as in the Zagros or southern Lut.

The position shown for the Lut is also highly speculative. The Mesozoic stratigraphic, magmatic and structural evolution of the Lut shows some differences from Central Iran. This may support the hypothesis that both blocks travelled separately across Neotethys. It must be emphasized that structural continuity between the southern Baluchestan and the Oman-Zagros ophiolites in spite of their similar Late Cretaceous age is not supported by either petrological or tectonic evidence.

In the Afghanistan-Pakistan composite block, the Turkman-Farah and Helmand blocks are only outlined in the figure; details of their evolution have been discussed by BASSOULET *et al.* (1980) and BOULIN (1981). India is shown as starting its drift toward Eurasia, a movement that begun about 130 Ma ago according to JOHNSON *et al.* (1976). The Tibet and the Indus-Tsangpo suture have been omitted. Madagascar had probably attained its present position alongside Mozambique, which it did by 80 Ma according to VEEVERS *et al.* (1980) and POWELL (1979).

At about 192 Ma, Jurassic-Triassic boundary (fig. 4).

At the Jurassic-Triassic boundary, India and Madagascar were still attached to the African plate, in their original Gondwanian position, in the southern Somalia basin (e.g. EMBLETON and VALENCIO, 1977; POWELL, 1979; VEEVERS *et al.*, 1980). Spreading at the Paleotethys ridge (dashed in the figure), if it ever existed, had stopped as a consequence of the Early Kimmerian (Late Triassic) orogeny, while the Neotethys ridge started to be active. The Gondwanian fragments that later formed Central Iran, Lut and

Afghanistan had separated from main Gondwana as a consequence of early Kimmerian dislocation, and according to palaeontological evidence some of these fragments (Central Iran and northern Afghanistan) were already linked to Eurasia (STÖCKLIN, 1974).

The position shown in fig. 4 for the continental fragments are highly hypothetical. Was Central Iran, though connected by shallow waters or lands to Eurasia, located still not far from the northwest margin of Arabia? Did the Lut originally fill the gap between Arabia and India (as first suggested by DIETZ and HOLDEN in 1970)? If this was the case, was the Helmand block of southern Afghanistan in front of India, as shown on the figure? The position has to explain the observed similarities in the stratigraphic record of both Afghanistan and Central Iran. The Turkman-Farah block of northern Afghanistan is shown close to Eurasia, to which it may have accreted as early as in Early Kimmerian time. However, it must be remembered that available stratigraphic and structural evidence, relevant to suturing in northern Afghanistan, is similar to Central Iran, which is shown farther away from Eurasia owing to the lack of any Late Kimmerian suture.

CONCLUDING REMARKS

In many previous palaeogeographic-palaeotectonic reconstructions of the Alpine area and northeastern Gondwana, Iran, Lut and Afghanistan have been shown as a single continental mass, part of either Eurasia or Afro-Arabia until the collision of both supercontinents during Tertiary times. However, ophiolitic and melange sutures actually show that the Middle East region has to be considered as a jig-saw puzzle of microplates between Eurasia, Arabia and India. The fragments were detached from northeastern Gondwana and accreted at different times to Eurasia. The Red Sea rift and the Owen-Murray ridge-Chaman fracture zone delineate progressive accretions to Eurasia, accretions which occurred in Late Paleogene times (eastward: with India) or in the Neogene (westward: Arabia-Central Iran). Repeated collisions between continental plates, or between continents and arcs, produced a mosaic that was readjusted many times. The Middle East may not be a peculiar case in the Alpine belt; current investigations have given analogous pictures in neighbouring areas and other parts of the Alpine belt may finally reveal a similar, though more concealed, evolution to that of the Near and Middle East.

Many points, however, remain obscure, in particular the northeastern boundary of the Central Iran block and the relationship of the Sabzevar ophiolitic belt, as well as the palaeotectonic significance of the subdivisions of the Lut block through faults and melange-ophiolite zones. The different vergences which may be inferred for Late Cretaceous ophiolite emplacement (upon, or away from, continental blocks accreting to Eurasia) are also not fully understood. Cretaceous subduction of oceanic crust may be considered as consistently dipping under Eurasia, or under fragments accreting to Eurasia, but ophiolite obduction may have resulted from mechanically different processes, where the nature of the colliding elements (continent, island arc, oceanic plate, etc.) may have been a controlling factor.

Moreover, the position during Mesozoic times of the Gondwanian fragments, that currently form the Middle East, is far from being precisely established. The most problematic fragment is the Lut block, where geological data tend to show a Mesozoic-early Cainozoic evolution somewhat different from both Central Iran and Afghanistan. Palaeomagnetic measurements will be helpful in the solution of these problems, as will be more petrographic, stratigraphic and structural correlations between the Gondwanian fragments.

From the above discussion a distinction appears to arise, from both chronological and dynamical standpoints, between ophiolite emplacement and continent-continent suturing, the latter possibly devoid of any ophiolitic signature. On a global scale, emplacement of ophiolites, which recent geochemical investigations show to be related more commonly to island-arc than to ridge-generated crust, appears in many cases to be a side-effect with respect to the evolution of an ocean, just as island arcs and marginal basins are tectonically. The greater part of typical, ridge-generated crust may be inferred to have disappeared into the mantle in the past as it currently does, the trace effect of this process upon continents being a magmatism of Andean type, but no incorporation of ophiolite. This distinction also helps to explain the volumetric disproportion between the restricted ophiolitic occurrences and the amount of oceanic crust inferred for the past by palaeomagnetic measurements and geological correlations.

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