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Artikel: Serpentinites, gabbros and ophicalcites in the Piemont-Ligurian domain of the Western Alps : possible indicators of oceanic fracture zones and of associated serpentinite protrusions in the Jurassic-Cretaceous Tethys

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SERPENTINITES, GABBROS AND OPHICALCITES IN THE PIEMONT-LIGURIAN DOMAIN OF THE WESTERN ALPS: POSSIBLE INDICATORS OF OCEANIC FRACTURE ZONES AND OF ASSOCIATED SERPENTINITE PROTRUSIONS IN THE JURASSIC-CRETACEOUS TETHYS

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ABSTRACT

Serpentinites of the Piemont-Ligurian domain are sometimes overlain by gabbros and/or basaltic pillow-lavas, followed by Upper Jurassic radiolarites and limestones. But very often the latter sediments lie directly upon serpentinites and various ophicalcites: this implies presence of extensive serpentinite submarine outcrops in this sector of the Tethys, believed to result from faulting. Moreover, numerous ophiolitic blocks occur as olistoliths in Upper Jurassic, and even more in Lower Cretaceous sediments of some epi-ophiolitic series: they are believed to originate from tectonically active submarine fault-scarps. Most consist of serpentinite containing rounded bodies of often foliated gabbros of many sizes. Global tectonic constraints suggest that in this sector of the Jurassic-Cretaceous Tethyan ocean both spreading and strike-slip faulting occurred simultaneously. It is therefore proposed that these "gabbro-balloons" bearing serpentinites derive from protrusions associated with oceanic fracture zones such as those of the Equatorial Atlantic, and that processes such as serpentinite diapirism, tectonization and metamorphism of ophiolitic rocks, etc., which seem to be specific of oceanic transform zones, may have been responsible of ophiolite generation in this part of the Tethys.

RÉSUMÉ

Les serpentinites du domaine Liguro-Piémontais des Alpes Occidentales sont parfois recouvertes de gabbros et/ou de basaltes en coussins, mais la couche basaltique manque souvent, d'où repos direct des radiolarites et calcaires du Jurassique supérieur sur des gabbros et surtout sur des serpentinites, par l'intermédiaire de brèches ophicalcitiques: ceci implique l'existence, dès le Jurassique moyen-supérieur, de fonds océaniques ultrabasiques assez étendus. Par ailleurs, les sédiments du Jurassique supérieur et surtout du Crétacé inférieur de certaines séries épi-ophiolitiques contiennent des olistolithes d'ophiolites où dominent des serpentinites à boules de gabbros parfois foliés: ceci implique l'existence d'escarpements de failles sous-marines actives faisant affleurer ces

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roches. Compte tenu des données de la tectonique globale, impliquant à cette époque et dans le secteur considéré à la fois expansion et décrochement sénestre, une comparaison est faite avec les fractures transformantes de l'Atlantique Equatorial, où la genèse de la croûte océanique relève de phénomènes particuliers, avec diapirisme de serpentinites, tectonisation et métamorphisme des ophiolites, magmatisme particulier. On suggère que des processus analogues ont pu être à l'origine de la genèse du substratum ophiolitique de ce secteur particulier de la Téthys mésozoïque.

1. INTRODUCTION

In this paper, ophiolites of the Western Alps will be taken from the point of view of the field geologist, without any petrological consideration: we shall therefore deal principally with the significance of either sedimentary or tectonic contacts between ophiolites and their sedimentary envelope. Thus, also taking into consideration certain constraints of Tethyan global tectonics as well as modern data from present-day oceans, a preliminary model of ophiolite emplacement in the Alps-Apennines sector of the Mesozoic Tethyan ocean will be proposed. Of course, such a model requires confrontation both with petrological studies and with further field research.

Field examples will be chosen in the Piemont zone of the Western Alps, especially in the vicinity of the town of Briançon (Chenaillet massif and Queyras mountains: Fig. 2).

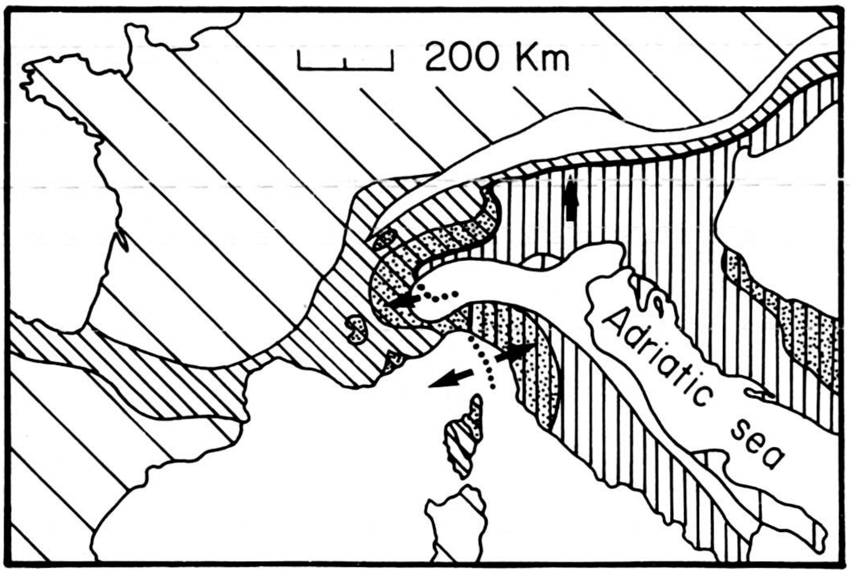

FIG. 1. — Sketch showing the Alps-Apennines sector of the peri-Mediterranean Alpine chains.
Oblique hatching: European continental block, including the Iberian and Corso-Sardinian blocks. Vertical hatching: Apulian block.
Closely spaced hatching: areas where the continental margins are involved in Alpine folding. Dots: domains where tectonic outliers of ocean-originating rocks (ophiolites and their sedimentary cover) can be observed.

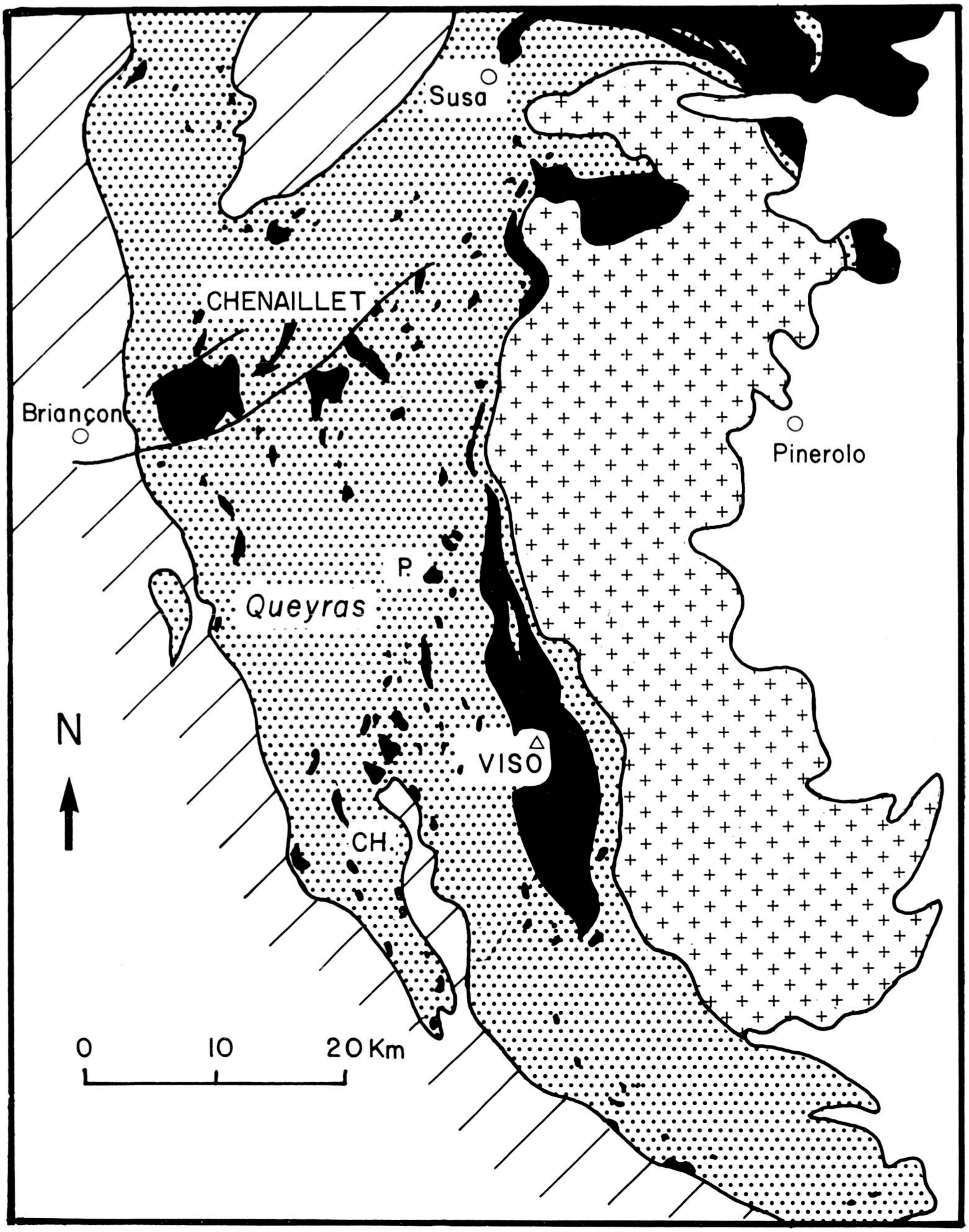

FIG. 2. — Structural map of the Cottic Alps in the Western Alps.
Oblique hatching: Briançonnais zone.
Crosses: Pre-Triassic crystalline Dora-Maira Massif.
Dots: Piemont zone or zone of the Schistes lustrés. Black: ophiolites.
P, Pelvat d'Abriès. CH, Chabrière.

2. PIEMONT-LIGURIAN OPHIOLITES OF THE WESTERN ALPS AND THEIR SEDIMENTARY COVER: REMNANTS OF THE JURASSIC-EARLY CRETACEOUS TETHYS IN THE ALPS-APENNINES TRANSECT

It is now generally agreed that ophiolites of the Alps, of Corsica and of the Apennines are remnants of oceanic crust and of upper mantle of the so-called Piemont-Ligurian ocean-crust-bearing domain ("ocean") which is part of the Jurassic Tethys. All these ophiolitic remnants, associated with preserved parts of their sedimentary cover, occur as overthrust structural units which lie upon the deformed continental margins (Fig. 1).

In the Western Alps, both ophiolites and overlying sediments occur in the so-called Piemont zone or "Schistes lustrés" zone (Fig. 2). The Schistes lustrés are epi- to meso-metamorphic, strongly folded sediments (mainly calcschists) where several different sedimentary series can be distinguished (Bourbon *et al.*, 1979) which belong to two main groups: (1) the epi-sialic (continental margin) Schistes lustrés series, and (2) the epi-ophiolitic (ocean) Schistes lustrés series (Fig. 3).

We shall henceforth deal only with the latter, i.e. with the Chabrière series (Fig. 3) and its equivalents, which originate from the Piemont-Ligurian "oceanic" domain.

3. FIELD OCCURRENCE OF OPHIOLITES

The everywhere overthrust Piemont-Ligurian structural units of the Western Alps generally comprise a complex ophiolitic base and a Jurassic-Cretaceous sedimentary cover (Fig. 3, 5).

3.1. *Ophiolitic base*

The ophiolitic association in the Western Alps is mainly made up of ultrabasites (mostly serpentinites), gabbros, and diabases with or without pillow structures, i.e. the classical Steinmann trilogy. Associated with this trilogy are minor bodies of trondjemites, rodingites, ophispherites, etc., which generally occur either as dykes or as "inclusions" in the serpentinites.

But this trilogy very rarely occurs in a complete and "normal" (i.e. theoretical) succession showing, from bottom to top, ultrabasites, gabbros, pillow-lavas. Of course some of the "anomalies" in the spatial organisation of these rock masses may result from Alpine tectonic disturbances; but, after eliminating these tectonic overprints, there still remain several anomalies certainly caused by "oceanic" pre-sedimentary and syn-sedimentary events:

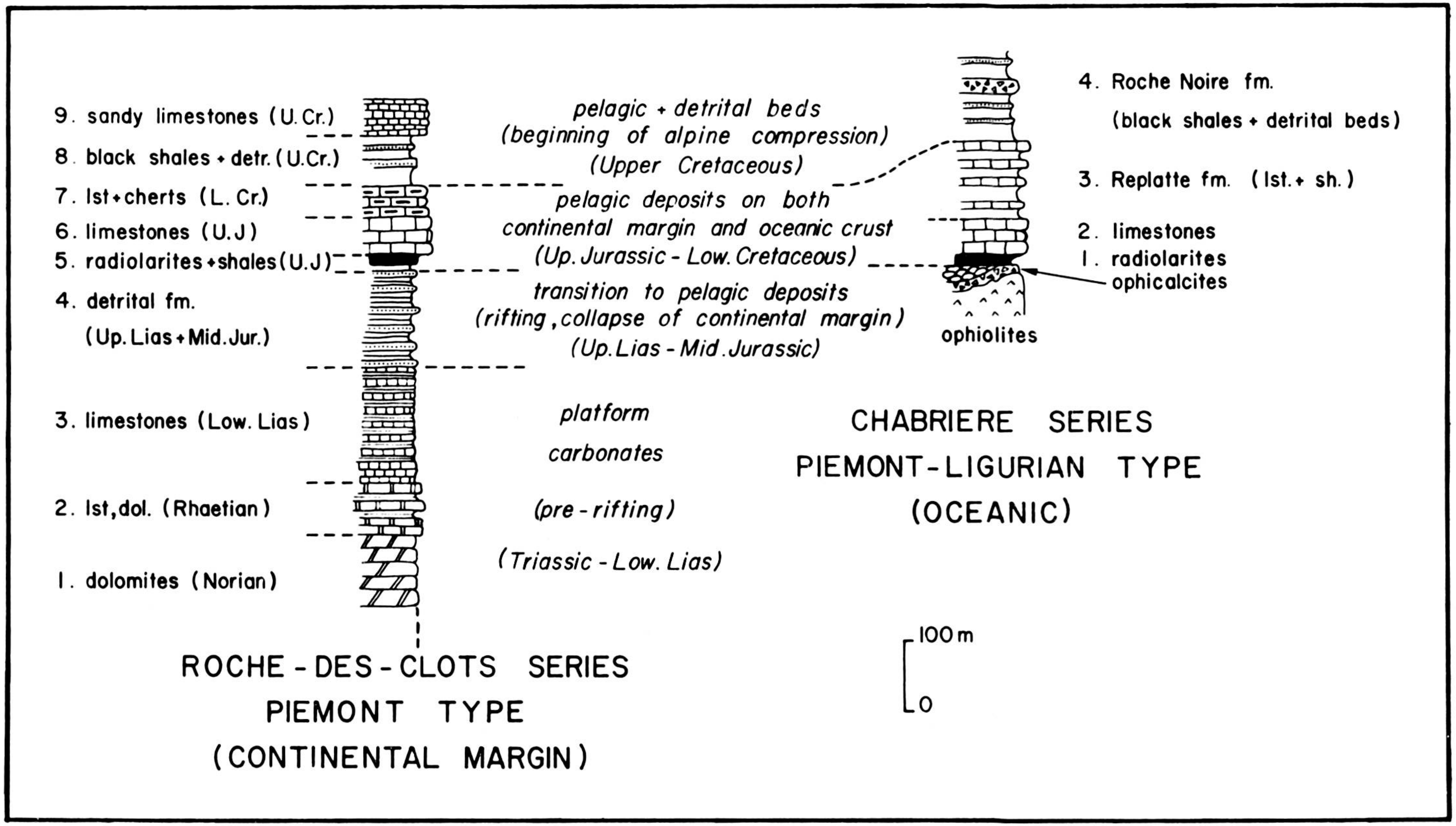

FIG. 3. — Examples of the tow main groups of sedimentary series in the Schistes lustrés zone of the Western Alps.

The Piemont structural zone, or Schistes lustrés zone, comprises several structural units with several different stratigraphic series, belonging to two main groups: the epi-sialic Schistes lustrés series (Piemont type s.str.: continental margin), and the epi-ophiolitic Schistes lustrés series (Piemont-Ligurian type: ocean).

a. *Pillow-lavas do not form a continuous layer;* their thickness varies from a few hundred metres (Chenaillet and Chabrière massifs) to a few metres or less; very often they do not appear at all so that the sediments (radiolarian cherts or limestones) lie directly upon gabbros and especially upon serpentinites.

b. *Breccias (ophibreccias)* with ophiolitic (mainly serpentinites) components and carbonate matrix, which are part of the so-called *ophicalcites*, very often occur at the top of gabbros or of serpentinites, i.e. at the base either of the pillow-lavas or of the sediments.

c. *Gabbros* are very scanty, and they also do not form a continuous layer. They are very often cut by diabase dykes. In certain outcrops, these gabbros are foliated as a result either of Alpine (Upper Cretaceous-Tertiary) compressional tectonics or of oceanic pre-sedimentary (Jurassic) "distensional" or wrench tectonics; the latter case is evidenced by diabase dykes cutting the already foliated gabbro (Steen *et al.*, 1977; Mevel *et al.*, 1978; Lemoine and Tricart, 1979). At certain places (ex. Pelvat d'Abriès in the Queyras mountains) the sediments directly overlay these gabbros.

d. *Ultrabasites* are always *serpentinites.* They are cut by dykes of often rodingitized gabbros or diabases; serpentinites also often contain "inclusions" varying in size (from a few centimetres to several hundred metres) as well as in lithology (gabbros, diabases, trondjemites, etc.); these inclusions may have undergone some metasomatism (ex.: ophispherites; rodingites). Some of these, especially the ophispherites, occur in sheared serpentinite zones which may have been linked with fractures affecting the Jurassic sea-floor (Bertrand *et al.*, 1980).

In short, three main groups of field observations must be emphasized:

— evidence for a *pre-sedimentary*, *"oceanic" tectonic activity* (e.g. the diabase dykes cutting foliated gabbros);

— occurrence of ophibreccias, implying submarine erosion, probably due to crumbling down of *submarine fault-scarps*;

— variable nature of the ocean-bottom upon which the first sediments were deposited: absence of a continuous basaltic layer, coupled with presence of *extensive areas with serpentinite sea-floor.*

3.2. *Sedimentary cover*

The Piemont-Ligurian oceanic domain is characterized by a Jurassic-Cretaceous sedimentary series which can be observed with only minor lateral modifications from the Northern Apennines (Bracco series) to Corsica (Inzecca series), and to the Western Alps (Chabrière series). Scarce microfaunas from the Apennines allow age determination of the main stratigraphic subdivisions. These ages are generally extended to the equivalent Corsican and Alpine series, neglecting a probable, minor diachronism linked with oceanic spreading. The Chabrière series (Fig. 3) therefore comprises (1) Upper Jurassic Radiolarian cherts (which may be absent in certain sections), (2) Upper Jurassic limestones, (3) Lower Cretaceous shales and limestones (Replatte formation, equivalent of the Palombini shales of the Apennines), and (4) Upper Cretaceous shales and sandstones (Roche Noire formation, equivalent of the Val Lavagna shales in the Apennines).

Olistoliths of serpentinites and gabbros in the Upper Jurassic (?)-Lower Cretaceous sediments: In some areas the Lower Cretaceous shales and limestones contain at different stratigraphic levels minor detrital beds with ophiolitic material, and numerous ophiolite blocks of various sizes (from a few tens of centimetres to several hundred metres) which are regarded as olistoliths (Lemoine and Tricart, 1979). Analogous but less frequent occurrences of debris and of blocks in the Upper Jurassic limestones are likely but not yet definitely proved. All these facts imply *the existence, in this sector of the Jurassic-Cretaceous Tethys, of syn-sedimentary fault-scarps which underwent several stages of tectonic activity.*

Moreover, basalts, radiolarian cherts, and limestones are all very scarce among these olistoliths most of which are made up of serpentinites containing rounded blocks of gabbros of many sizes (from several metres to several hundred metres); these "gabbro-balloons" are known either in their sheared or not sheared serpentinous matrix, or isolated in the sediments; they are often foliated and, at least in some cases, foliation seems to be early since it is cut by diabase dykes. Therefore *the submarine scarps were mostly made up of serpentinites with rounded mega-inclusions of either foliated or non-foliated gabbros:* this must be kept in mind when looking for an actualistic model (par. 5).

3.3. *Summing up: Specific features of ocean-bottom generation and evolution in the Piemont-Ligurian "ocean":*

Both Piemont-Ligurian ophiolites and their sedimentary cover in the Piemont zone of the Western Alps bear the mark of tectonic events which may be either linked with the first appearance of an ophiolitic sea-floor ("pre-sedimentary" tectonics), or coeval with the Upper Jurassic-Lower Cretaceous spreading ("syn-sedimentary" tectonics).

Pre-sedimentary tectonic events: Tectonization (and metamorphism) of some foliated gabbros, possibly also of some foliated serpentinites (with formation of ophispherites?); appearance of a serpentinous sea-bottom, accompanied by formation of submarine relief (fault-scarps: ophibreccias).

Syn-sedimentary tectonic events: Evolution of the already existing submarine fault-scarps, or birth of new ones.

Similar "anomalies" have been reported from the Northern Apennines (Gianelli and Principi, 1977; Cortesogno *et al.*, 1978). Finally, all these facts strongly suggest that the features specific to the Piemont-Ligurian "ocean" require a special genetic explanation.

4. GLOBAL TECTONIC CONSTRAINTS: THE ORIGINALITY OF THE PIEMONT-LIGURIAN "OCEAN"

Briefly speaking, one may consider the Mesozoic Tethys as a more or less latitudinal oceanic domain comprized between Laurasia and Gondwania. From East to West one may distinguish (Fig. 4): (1) a complex and partly mysterious *Eastern Tethys*, situated to the East of the Apulian-Adriatic continental block *(Apulia)*; (2) the *Western-Mediterranean Tethys*, including the Piemont domain; (3) the *Atlantic Tethys*, i.e. the early Central Atlantic; (4) the *Caribbean Tethys*. The shape and width as well as the evolution in time of these different Tethyan sectors are rather difficult to reconstruct. Nevertheless a relatively rough approach can be found in the kinematic evolution of its continental frame which depends on the successive stages of opening of the different sectors of the Atlantic ocean [1]: Central Atlantic (–180 m.y.), South Atlantic (–130 m.y.), North Atlantic (–100 m.y.).

If one agrees with these plate tectonic results, the motion of Africa relative to Europe appears to have been, between –180 m.y. (Early Jurassic) and –100 m.y. (Mid-Cretaceous), a left-lateral strike-slip movement over about 2,000 kilometres [2].

However, the southern margin of the Piemont-Ligurian sector of the Mesozoic Tethys was not Africa but *Apulia*. Whether this small continental block may be taken as a "promontory" of Africa, or as an independent microplate affected or not by rotation, will not be discussed here. But it is very likely that the motion of Apulia relative to Europe has been also a left-lateral one during Jurassic-Lower Cretaceous times.

Finally both the inferred relative motion and the gross shape of Apulia (see Figure 4) strongly suggest that on the western side of this continental block *the Piemont-Ligurian domain, between –180 and –100 m.y., was the site both of opening followed by sea-floor spreading, and of rather widespread strike-slip faulting.*

[1] Of course, such a reasoning process is perfectly valid, but we must bear in mind that it implies (1) total confidence in the significance and the identification of the magnetic anomalies in the Atlantic ocean, and (2) acceptance of the postulate of permanency in time both of gross chape and of surface of the main continental masses.

[2] Whereas, from —100 m.y. on, Africa drew near Europe, leading to the disappearance of the Piemont-Ligurian ocean followed by continent collision.

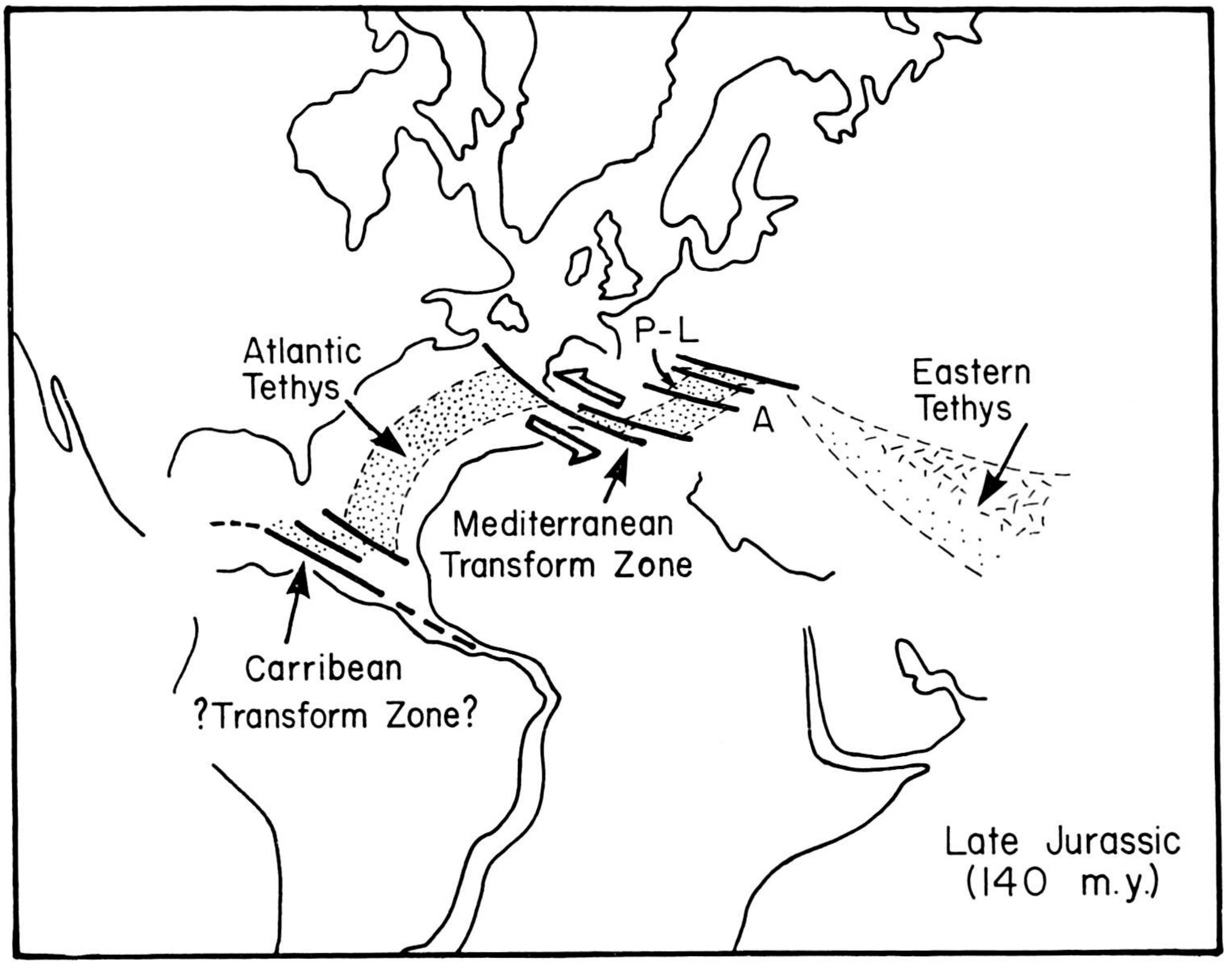

FIG. 4. — Tentative palinspastic sketch of the Late Jurassic Tethys.

Dots: oceanic crust areas. The relative positions of the main continents are taken from Smith and Briden (1977, map 9). For the palinspastic set up of the Piemont-Ligurian domain, and more generally of the Jurassic Tethys, see also Elter and Pertusati (1973, Fig. 1 A), Trümpy (1976, Fig. 3), Laubscher and Bernoulli (1977, Fig. 5), Bernoulli and Lemoine (1980, Fig. 3).

The Eastern Tethys was a complex domain, probably with both oceanic and continental crust areas the kinematic evolution of which remains difficult to decipher. The Atlantic Tethys was the early Central Atlantic Ocean, with simple normal spreading since Early Jurassic times.

Inserted between the latter, and to the East of the Atlantic Tethys, were two complex domains where both spreading and intense (left lateral) strike-slip faulting occurred: (1) The Mediterranean Tethys, comprising the Piemont-Ligurian "ocean" (here tentatively shown as a "rhombochasm") may be considered as a mega-transform zone between the Atlantic Tethys (which was at that time subject to spreading), and the Eastern Tethys (where more complex movements occurred at that time). (2) The Caribbean Tethys, which probably played an analogous part.

A, Apulia. P-L, Piemont-Ligurian oceanic domain.

5. POSSIBLE MODEL: TRANSFORM FRACTURE ZONES OF THE EQUATORIAL ATLANTIC OCEAN

As a matter of fact, the sedimentological and paleotectonic evolutions of the European passive continental margin of this part of the Mesozoic Tethys are highly comparable to, if not identical with, those of the Atlantic ocean (de Graciansky *et al.*, 1979). Nevertheless, data concerning the Piemont-Ligurian ophiolites (par. 3 above) as well as other data which will be discussed in a forthcoming paper, suggest that a simple "Atlantic-type" model of spreading, the spreading direction being nearly perpendicular to the continental margin, cannot account for all known data.

In fact, as suggested in paragraph 4, a better actualistic model might be chosen in an area where *both* spreading *and* rather closely packed strike-slip faulting occurred simultaneously. Such areas are well known in present-day oceans, such as the Gulf of Southern California, the Cayman zone in the Caribbean, the Knipovitch ridge to the North of the Norwegian sea, or, above all, the transform fracture zones of the Equatorial Atlantic ocean (Vema, Saint Paul, Romanche, Chain, Charcot, etc.).

These latter fracture zones originated from a right-lateral strike-slip motion of Africa relative to South America. This motion began somewhat later (Early Cretaceous) than, but is the symmetrical (mirror image) of, the left-lateral "Mediterranean" (Fig. 4) strike-slip zone which took place between Africa and Europe on and after the Early Jurassic. But this Mediterranean zone (which includes the Piemont-Ligurian "ocean") has been subsequently destroyed by Alpine compression whereas

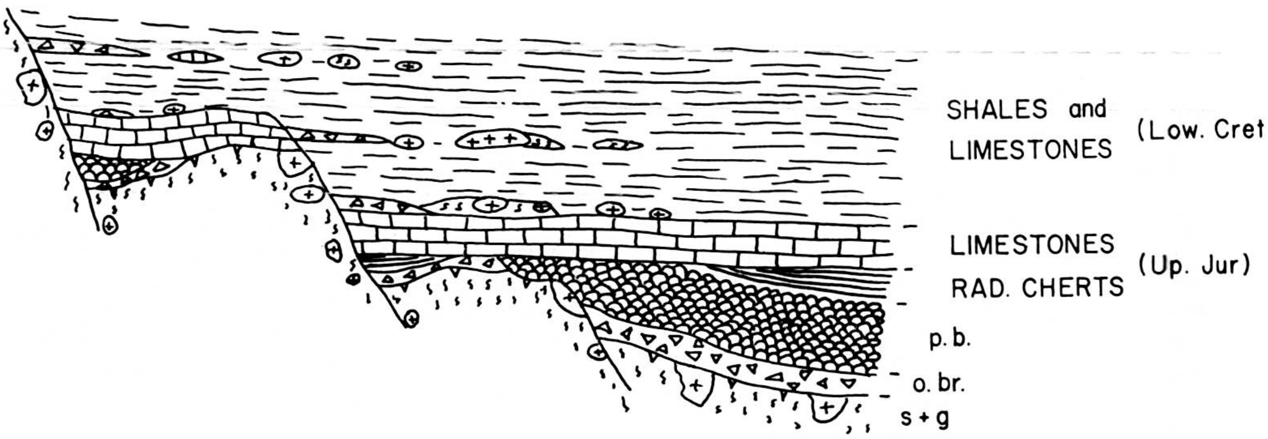

FIG. 5. — Theoretical diagram showing inferred relations between ophiolites and their sedimentary cover in the Piemont-Ligurian domain.

The active submarine fault-scarps shown in the diagram are supposed to be result from uplift of a serpentinite protrusion linked with a transform fault zone.

s, serpentinites; g, gabbros (crosses); o br, ophibreccias; p b, pillow basalts.

the Atlantic ocean remains undisturbed but for being enlarged through continuing spreading.

The main physiographic, tectonic and lithologic features of these Atlantic transform zones are as follows:

These zones are elongated (several thousand kilometres) and relatively narrow (tens to hundreds of kilometres); they are tectonically active, since they are the site of earthquakes, and also because their topography changes in time (Bonatti, 1978).

This topography is governed by "transverse" ridges and troughs more or less parallel to the direction of the transform faulting. The troughs are filled up with a thick sedimentary series, whereas the bed-rock of ridges and scarps frequently outcrops, so that it can be dredged or even observed and sampled with a diving saucer. The outcrops mostly consist of serpentinites, associated with gabbros and metagabbros, also with basalts together with some sediments, including ophibreccias (Bonatti *et al.*, 1974); consequently, ophiolite-derived detrital sedimentation takes place on the slopes (Bonatti *et al.*, 1973; Choukroune *et al.*, 1975; etc.).

All these data are consistent with those presented in paragraph 3, so that the model appears to be fitting, especially if one considers the earliest phases of opening and of spreading: the Equatorial Atlantic in being was then relatively narrow (some hundreds of kilometres to one or two thousand kilometres) and cut up by a set of nearly parallel fault scarps, ridges and troughs.

The presence of these elongated serpentinite ridges has been interpreted as the result of diapiric uplifts ("protrusions") of serpentinite in the strike-slip zone (Bonatti, 1976). Information provided by a sample dredged on the Vema serpentinite transverse ridge (shallow-water marine limestone of probable Upper Jurassic or Lower Cretaceous age, containing detrital debris of continental-crust origin) (Bonatti and Honnorez, 1971; Honnorez *et al.*, 1975) suggests that such protrusions may appear rather early in the history of the ocean opening, possibly as early as the very beginning of the separation of the continental masses: similar mechanisms may be able to explain the early appearance of serpentinite sea-bottom and coeval submarine faulting in the incipient Piemont-Ligurian "ocean".

6. CONCLUSIONS

To sum up, the major physiographic, tectonic and lithologic features of the Equatorial Atlantic fracture zones provide a model which fits well what we know about the ophiolites and overlying sediments of both Apennine (Gianelli and Principi, 1977; Cortesogno *et al.*, 1978; DeLong *et al.*, 1979) and Alpine parts of the Piemont-Ligurian oceanic domain; similar comparisons have been made in other folded belts, as for example in California, where similar rounded blocks of gabbros or diabases occur in the serpentinite mélange (Saleeby, 1979).

Of course, serpentinite diapiric protrusions as well as gabbro outcrops are known from areas near mid-ocean ridges with no or only minor strike-slip faulting, but they then seem to be less frequent and less abundant; moreover, for the here-considered sector of the Tethys, global tectonic constraints imply predominance of strike-slip movements.

Finally, this "transform zone model" accounts for the "not classical" rock assemblage and spatial set up of both Northern Apennines and Western Alps ophiolites, as well as for the "abnormal" composition and structure of oceanic crust in present-day transform fracture zones (Francheteau *et al.*, 1976). These specific features appear to result from combination of such processes as serpentinite diapirism, tectonization plus metamorphism of the ophiolitic rocks, coupled with a certain amount of magmatism (especially alkali basalts: Prinz *et al.*, 1976) — that is, of specific processes of ocean crust generation which seem to be restricted to oceanic fracture zones (Bonatti and Honnorez, 1976; see also Van Andel *et al.*, 1969; Menard and Atwater, 1969: "leaky transforms"). As recently suggested by Ohnenstetter (1979) for Corsican ophiolites, it is here proposed that such processes specific of oceanic transform fractures may be responsible of ophiolite generation in this sector of the Mesozoic Tethys.

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