

Zeitschrift: Eclogae Geologicae Helvetiae
Herausgeber: Schweizerische Geologische Gesellschaft
Band: 67 (1974)
Heft: 3

Artikel: The ophiolitic mélange, a world-wide problem on tethyan examples
Autor: Gansser, Augusto
DOI: <https://doi.org/10.5169/seals-164302>

Nutzungsbedingungen

Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. [Siehe Rechtliche Hinweise.](#)

Conditions d'utilisation

L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. [Voir Informations légales.](#)

Terms of use

The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. [See Legal notice.](#)

Download PDF: 29.01.2025

ETH-Bibliothek Zürich, E-Periodica, <https://www.e-periodica.ch>

The Ophiolitic Mélange, a World-wide Problem on Tethyan Examples

By AUGUSTO GANSSER¹⁾

ABSTRACT

The ophiolitic *mélange* is defined as a olistostromal and tectonic mixture of ophiolitic material and sediments of oceanic origin with exotic blocks, reflecting areas which have subsequently disappeared. Being intimately related to ophiolitic belts they indicate important suturelines connected to plate boundaries. Ophiolitic *mélanges* occur mostly where continental type plates are subducted with obduction of oceanic material. These facts are discussed on examples from the Middle East and the Himalayas, where the *mélanges* are particularly well exposed.

1. General aspect

81 years ago, a famous trio of geologists, C. L. Griesbach, D. Diener and C. S. Middlemiss, sponsored by the Geological Survey of India, visited the Kiogar area at the border between Kumaon and Tibet in the Central Himalaya. In this fascinating, remote and barren area, lying between 5000 and 6000 m above sea level, they were puzzled by a most unexpected geology. Above competent folds in the well known Spiti sequence they observed a wild jumble of flysch-type sediments, together with foreign looking blocks from a few meters to several thousand meters in size, intricately mixed with basic and ultrabasic rocks. After a preliminary investigation of this area and a vivid discussion with his colleagues, well known for their great Himalayan experience, Diener came to the following conclusion (DIENER 1895, p. 604):

«Fünf Momente sind für die Klippen von Chitichun und am Balchdhura bezeichnend: 1. Die von der Hauptregion des Himalaya abweichende Schichtfolge; 2. die bogenförmige, diagonal auf das Streichen der Himalaya-Falten verlaufende Streichrichtung; 3. ihr Auftreten innerhalb eines muldenförmigen, mit Flysch und Spiti Shales erfüllten Gebietes; 4. ihre innige Verbindung mit Eruptivgesteinen; 5. das Fehlen jedweder Art von Strandbildungen in ihrer Umgebung.»

He could not agree to a direct comparison with the Klippen of the Swiss Alps and Carpatians, but accepted in principle Bertrand's and Schardt's ideas as «*lambeaux de recouvrement*». His main difficulty was the interpretation of the presence of large

¹⁾ Geological Institute, Swiss Federal Institute of Technology and University of Zürich (Switzerland).

amount of basic rocks. Based on the available information he could not solve the problem as he stated at the end of his work (p. 606):

«Eine Lösung des tektonischen Problems der Klippen von Chitichun geben zu wollen, halte ich in Anbetracht der ungenügenden Kenntniss, die wir heute noch von der Ausdehnung jenes Phänomens besitzen, und bei dem Mangel einigermaßen brauchbarer Nachrichten über den geologischen Bau der angrenzenden Theile von Tibet für verfrüht. Es mag genügen, hier auf jene Eigenthümlichkeiten hingewiesen zu haben, welche die tibetanische Klippenregion von allen bisher in Europa bekannten Klippenzügen unterscheiden und dieselbe zu einem der interessantesten und merkwürdigsten Theile des Himalaya stempeln, der wie kaum ein anderer noch auf lange Zeit hinaus ein dankbares Feld für weitere Forschungen abgeben wird.»

Though this discovery was of outstanding interest, eight years elapsed before new action had been taken in connection with this fascinating problem. In spite of the scepticism of Dr. William King, then Director of the Geological Survey of India, A. von Krafft was ordered by the Survey to investigate this remote area during the summer season of 1900. During six weeks of intensive field work in the wider Kiogar area von Krafft gathered a wealth of most valuable information including rare fossil collections from various blocks, which, after a careful investigation by Diener, supported the foreign aspect of these faunas, unknown in this part of the Himalaya. Excellent panoramic sketches and photographs clearly outlined the contrast between lower and upper structural levels.

While DIENER (1895) compared the exotic Kiogar blocks to the Klippen of the Alps and the Carpathians, which at the time were newly discovered and thus of great general interest, VON KRAFFT (1902) saw no connection with Klippen and proposed as primary origin huge volcanic explosions in Tibet through which the sediments were mixed with the basic volcanics. He admitted, however, that these arguments were not fully convincing on the still scanty available facts. His stimulating discussions of pro and contra of his ideas bring out many of the problems which crop up during the present discussions of *mélange* rocks. On page 169 he wrote:

“Those which assume structural causes would imply that the exotic blocks were brought into existence by the disturbances which lead to the upheaval of the Himalayas. This, however, is not the case. We have seen that the volcanics, which include the blocks, were folded together with the flysch. From this we can only conclude that the volcanics and consequently also the exotic blocks were pre-existent to those disturbances, and any causal connection between the latter and the blocks is therefore impossible.

Nor is it at all conceivable that folding or faulting should have brought about those features, which were described in the above chapters. None of the theories alluded to would explain the presence of the volcanics and their intimate connection with the exotic blocks.”

It is most unfortunate to science that von Krafft was not able to continue his fascinating studies. He died 1901 in Calcutta. Though von Krafft has not coined the word “*mélange*”, his careful descriptions and discussions of a possible origin of the exotic rocks put him among the very first pioneers who stressed the importance of the *mélange* problem.

The first to mention ophiolitic rocks in southern Tibet north of the Kiogar region discussed above was Captain STRACHEY in 1851 (p. 308):

“A great outburst, in which are found hypersthene and bronzite, besides syenitic and ordinary greenstones, and various varieties of porphyry, occurs in the vicinity of the lakes which are found at the eastern extremity of the plateau. The greenstone is known to extend considerably to the west, and

forms, at an elevation of about 17,600 feet, the summit of Balch, one of the Himalayan Passes into Tibet which I have crossed.”

He stressed the structural difference between the granites of the Transhimalaya and the ophiolitic rocks (p. 309):

“The Granites appear to constitute lines of elevation, not of rupture; but there seems to be no specific action produced by them on the dip of the strata, which they appear to leave generally unchanged.

The Greenstones, on the other hand, usually follow lines of dislocation of the strata; being sometimes apparently contemporaneous, and at others intruded through rocks already consolidated.”

SUESS, in his famous *Das Antlitz der Erde* (1901, p. 352 ff.), recognized the importance of the extraordinary findings of the Himalayan geologists and devoted some chapters to this problem. He realized the significance of thrust movements and of Eocene volcanics along the Indus:

«Vielleicht war hier im Eocän eine mit Vulcanen besetzte Disjunctiv-Linie vorhanden» (1901, p. 351).

He connected this line with the exotic area of Kiogar, and he stated (1909, p. 648):

«Diese Erfahrungen lehren, dass die Verfrachtung der tibetanischen Schollen und das Hervortreten der simischen Gesteine zur gleichen Zeit eingetreten sind»

and on the same page:

«Balchadura [the Kiogar area] stellt den Rand einer Bewegungsfläche erster Ordnung dar, an welcher sedimentäre Serien von abweichender Facies sich überlagern.»

It is significant, that this particular zone was later recognized as one of the most important subduction zones of modern geology.

The term “mélange” (autoclastic mélange) was introduced by GREENLY in 1919 when he described a complicated tectonic mixture in the Precambrian Mona complex of Anglesey island in Wales. From his careful descriptions it is evident that his autoclastic mélange has strictly tectonic implications with no relations to ophiolitic type rocks. The tectonic aspect of a mélange is still widely propagated (Hsü 1968), but, as we will see, the question is much more complex and still most problematic.

The “mélange” has been revived in the Middle East, where excellent outcrops of this widespread phenomenon had eventually called the geologist’s attention. BLUMENTHAL, when mapping in Central Anatolia, described a “Mésozoïque à facies tectonique brouillé” (1948). This same facies was mentioned by BAILEY & MCCALLIEN as Ankara Mélange (1950, 1953). They used the term mélange “out of respect for descriptions that Greenly and Matley have furnished of a similar tectonic mélange in Anglesey...”. The detailed account of BAILEY & MCCALLIEN stressed the relation of exotic blocks to basic and ultrabasic rocks. They recognized Steinmann’s “Trinity” after having discovered pillow lavas and stressed the world-wide occurrence of ophiolitic rocks, failed, however, to include the mélange formation into this general picture. Although not mentioning mélange in particular, KÜNDIG (1959) gave the following characteristics of these ophiolite occurrences (p. 469):

- a) The great variety and mixture of hypabyssal, plutonic and volcanic rocks.
- b) The occasional association – unexplained so far – of metamorphic (Glaucophane rocks) and non-metamorphic rocks.

- c) An extremely complex, often chaotic imbricated structure frequently accompanied by overthrust sheets and nappes.
- d) The apparent scarcity or absence of magmatic channels and feeders to supply the effusions and intrusions.
- e) The scarcity or absence of thermal contacts with the embedding sediments; most contacts are apparently tectonic.
- f) The difficulty of an age determination of the *mise en place* of the igneous rocks, owing to the chaotic relation with, and scarcity of fossils in, the accompanying sediments.

While discussing the ophiolites of Celebes the same author located ophiolites as follows (KÜNDIG 1956 *b*, p. 229):

“The consequence is that, with the appearance of ophiolites in an orogenic belt, i.e. with the transition from the shelf- or mio-geosynclinal- into the eu-geosynclinal zone, facies and thickness of sediments change abruptly.

As the transition zone coincides with the old trench-slope, which developed in a subsequent diastrophic phase into a thrust-line of the first order, it frequently occurs that the trough-contents, namely the eu-geosynclinal facies, with its masses of ophiolites, are thrust over the facies of the shelf edge. Such cases are known from Turkey, Kurdistan, Oman and in East-Celebes.

The trench-slope is, particularly during the ophiolitic extrusions at depth, an area of catastrophic events. It is not only the site of turbidity currents, but during the buckling down, vast tracts of the shelf edge mantle may glide down and accumulate as huge exotic masses (e.g. *Mélange* of BAILEY 1953) in a foreign environment.”

When substituting miogeosyncline and eugeosyncline by continental and oceanic plates respectively, KÜNDIG's statements fit modern ophiolitic concepts remarkably well.

That the world-wide occurrence of the *mélange* rocks together with ophiolites is not sufficiently recognized is underlined by the fact that the recent Penrose Conference, dealing with ophiolites, did not include *mélange* in its terminology (anon. 1972). This unfortunate situation calls for reaction, and it is the purpose of this article to stress the world-wide importance of the *mélange* formations and their intimate relation to the ophiolite suite and thus their direct involvement in modern geotectonic theories. It is for this reason that the name *ophiolitic mélange* is proposed in order to distinguish it from purely sedimentary *mélange* of the olistostrome type or purely tectonic *mélange* in the original meaning of GREENLY.

My personal interest in the “*mélange*” arose in 1936 when I visited the Central Himalayan border regions, already described by VON KRAFFT, and followed these enigmatic outcrops into the “root zone” of the Himalaya in southern Tibet. They were described as an “Exotic Bloc zone” (HEIM & GANSSER 1939) and later, based on the excellent occurrences of the Middle East, as “Colored *Mélange*” (GANSSER 1955).

In order to stress the global importance of ophiolites with their related *mélanges*, the Commission of Structural Geology of the International Union of Geological Sciences chose this subject as its main working theme. During a special Ophiolite Symposium, held in USSR in 1973 and sponsored by the Academy of Science of the USSR as well as the Commission on Structural Geology, the *mélange* problem was the main topic and could be discussed on the basis of excellent outcrops in the western Tien-Shan and Kyzyl-Kum area (Paleozoic ophiolites) as well as in the little Caucasus (Mesozoic ophiolites). In both areas the relation of ophiolitic *mélange* to major tectonics is well exposed, and this topic received an excellent review in a recent

Russian publication by the members of the Academy of Sciences of the USSR, Moscow (1973), entitled *Developmental stages of folded belts and the problem of ophiolites* (see also Geological Newsletter 1973, Vol. 3, p. 211). Their acceptance of major thrusting in relation to mélange formations as a world-wide occurrence is new and most stimulating.

2. Definition of ophiolitic mélange

From the great amount of data published recently on ophiolites and their relations to global tectonics, the importance of the ophiolitic mélange is increasingly evident, and also the confusion regarding its definition. Hsü (1968) discussed the rock unit "mélange" in great detail and has the merit of stressing the structural importance of this complex formation. The recognition of the mélange as a mappable unit has helped to clear up many a confused situation, where before much care was taken to unravel a hopeless tectonic picture by carefully mapping single exotic blocks.

Hsü's definition does not, however, stress the intimate relation to ophiolitic belts. The mélange, as originally defined by GREENLY (1919), could be a tectonic feature only or also a purely sedimentary olistostrome complex. I would like to use the term *ophiolitic mélange* as the more widespread occurrence without, however, substituting the general term mélange by ophiolitic mélange. For this term I offer the following definition, which is based on many occurrences known to me personally or described in the literature. This definition is open to discussion, and I would welcome constructive criticism:

Factual and genetic characteristics of an ophiolitic mélange:

1. We recognize a mixture of rocks of the ophiolitic suite together with non-ophiolitic rocks often of unknown origin (exotic blocks).
2. The matrix of the mélange could be ophiolitic (frequently tectonically sheared serpentines) or sedimentary, the latter mostly of a flyschoid facies.
3. No contact metamorphism exists between components of a mélange, but metamorphic reactions can be locally important.
4. The base of a mélange is always a tectonic contact; the top is often marked by transgression of pelagic calcareous or flyschoid sediments.
5. The ophiolitic mélange results from a sedimentary (olistostromal) *and* tectonic mixture. (I would like to stress that such a mélange cannot have only a tectonic origin. This could not explain the intimate mixture of exotic blocks of very varied composition. See also GRACIANSKY, in press.)
6. During emplacement recycling occurs, including olistostromal slumping, tectonization and further incorporation of oceanic crust. A part of the mixing is related to this episode.
7. The ophiolitic mélange is restricted to ophiolitic belts and outlines zones of major structural significance (plate boundaries).
8. The final emplacement of a mélange body can be by diapiric protrusion and then the original connections to members of the ophiolitic suite become completely disrupted.

9. It thus can occur also when the classical ophiolitic suite is incomplete or totally missing and may outline geotectonic belts in the same way as an ophiolite zone would do.
10. In zones with strong allochthonous character the *mélange* horizon is often overthrust by ultrabasic sheets (Himalaya, Oman, Zagros, Taurus, Papua ?).
11. The ophiolitic *mélange* must be distinguished from normal olistostromes (ELTER & TREVISAN 1973), the latter being interbedded into a normal sedimentary sequence. These differences are for instant clearly expressed in southeastern Turkey (Fig. 3), though in strongly tectonized regions this distinction is admittedly difficult.

The broad characteristics and the regional setting of some ophiolitic *mélange* formations from Asian examples are discussed in the following:

3. General discussion of ophiolitic *mélange* formations

a) *The Oman mélanges*

The ophiolitic belt of Oman forms the eastern border of the Arabian shield. From here, *mélange* formations have been known for over 45 years through the excellent work of LEES (1928). His ideas about the allochthonous position of the Hawasina beds (*mélange*) and the separate ultrabasic nappe (Semail) have been confirmed by recent investigations (REINHARDT 1969, ALLEMANN & PETERS 1972, GLENNIE et al. 1973), while some authors follow a more autochthonous interpretation with uplifts and related gravity slides (MORTON 1959, TSCHOPP 1967, WILSON 1969). Based on these new though still incomplete investigations, we suggest an underthrusting (subduction) of the Arabian (African) plate, resulting in overthrusting (obduction) of the Oman oceanic slab on of the Arabian shield (Fig. 1). A parautochthonous sedimentary shield cover is "overthrust" by the Hawasina unit, a *mélange* nappe which was overridden by the relatively undisturbed Semail unit, where the classical oceanic sequences from ultrabasics to pillow lavas is locally preserved below the upper Maestrichtian transgression. The locally steeply dipping metamorphic slivers observed in northern Oman between Hawasina and Semail thrust sheets are difficult to place (ALLEMANN & PETERS 1972).

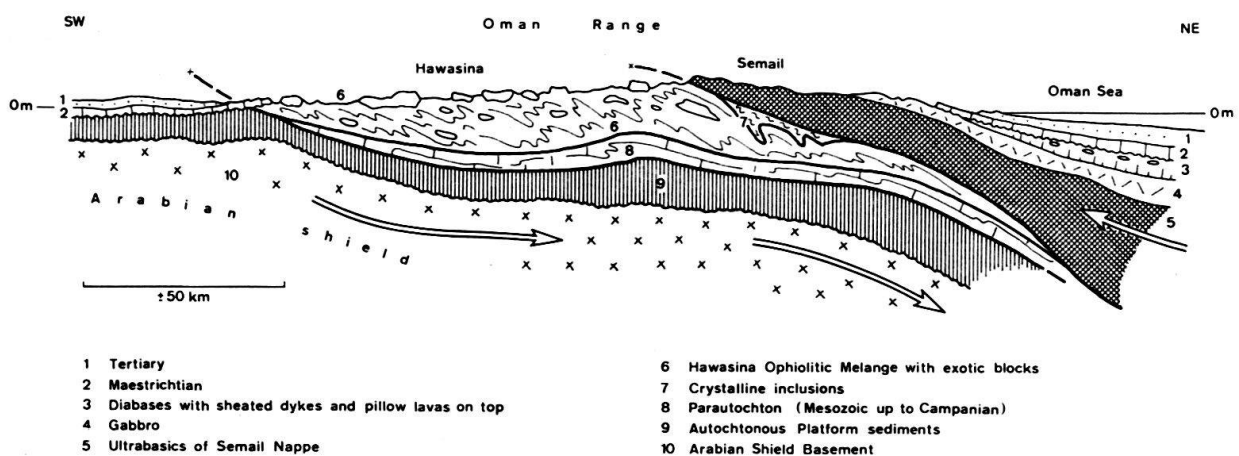


Fig. 1. Schematic section through Oman Mountains (compiled from various sources).

The youngest beds involved in the emplacement of the ophiolite nappes are Campanian to (?) lower Maestrichtian. In the Hawasina mélangé matrix a planktonic Cenomanian to (?) lower Turonian fauna indicates the youngest age (ALLEMANN & PETERS 1972), while the exotics range from Ordovician to middle Cretaceous with a predominance of huge Permian and Triassic blocks.

There is little doubt that the emplacement of the Oman ophiolitic nappes, including the mélangé sheet, falls between lower Turonian and middle Maestrichtian times. Unlike other orogenic belts, the later movements in Oman were only of a small scale. Whereas the foreland features of Oman are relatively clear, the backland covered by the Oman sea is still highly enigmatic. An oceanic crust seems to be covered by a pile of 4000 m of mostly clastic sediments of Neogene age, the top of which lies over 3000 m below sea level (HINZ & CLOSS 1969). Similarly to the Beluchistan coast north of the Oman sea they mask the important pre-Maestrichtian structural history.

While Oman was little affected by post-Cretaceous movements, the history following the reactions of the northern Arabian (African) plate with its Eurasian counterpart is highly involved. This is witnessed by the mountain fronts bordering the shield from Turkey over Iran into Afghanistan–Pakistan, a zone exposing some of the world's most striking ophiolitic mélangé occurrences (Fig. 2).

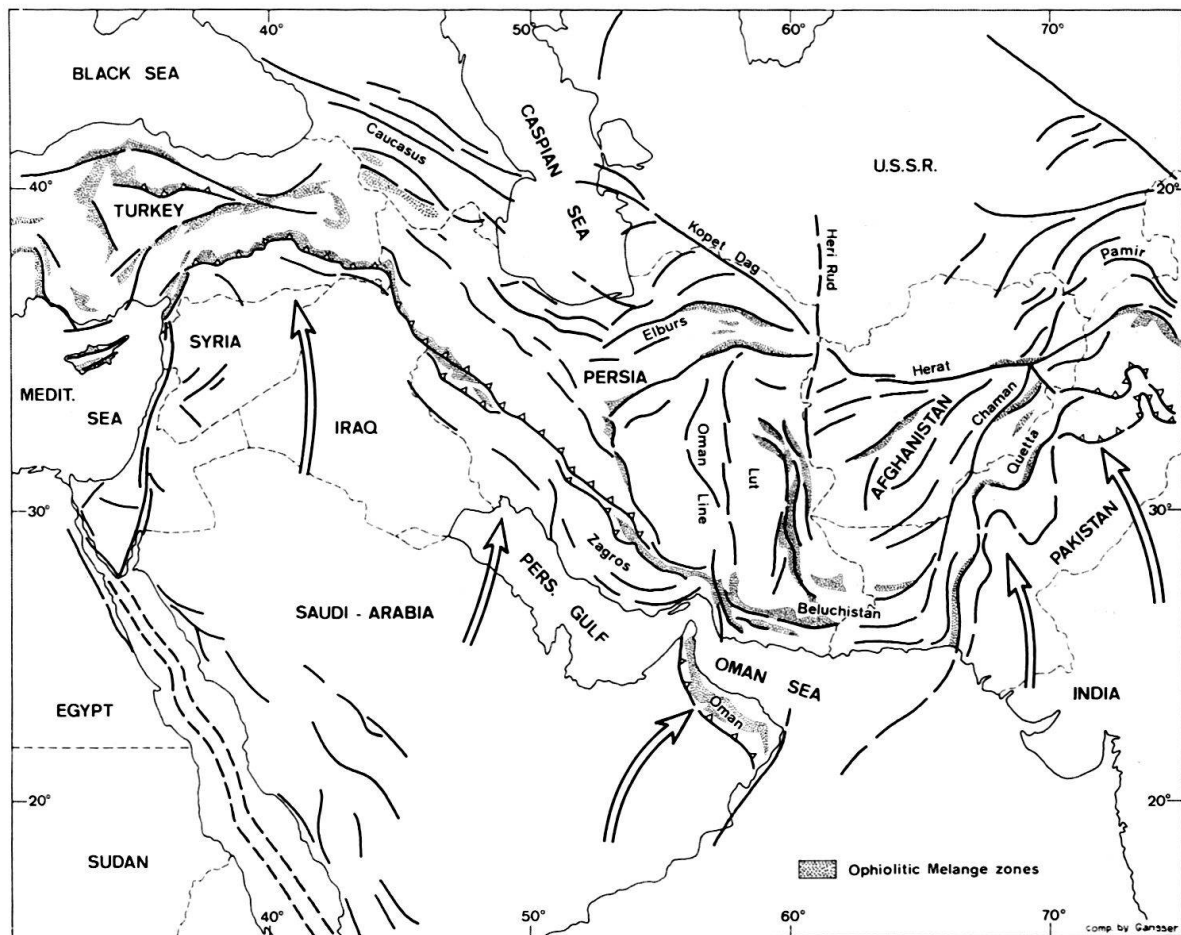


Fig. 2. The main structures of the Middle East.

b) *The Anatolian mélanges including Cyprus*

Turkey straddles the northern continuation of the western border of the Arabian shield, which contrasts strongly with Oman. This western edge coincides with the Levantine rift system, where Arabia has apparently moved in post-Cretaceous time relative to Africa over 150 km to the north (QUENNEL 1958, FREUND et al. 1968, 1970). Westwards from this structural north-south line conditions are strikingly different: The Mediterranean covers the actual African front and displays an oceanic ridge running in a west-east direction into Cyprus, which represents a part of this ridge rotated by 90°. The Kyrenia range in north Cyprus, with its large olistoliths, runs east-west and is thrust to the south forming a southernmost branch of the Taurids (DUCLOS 1964). This range occurs suspiciously near to our expanding oceanic ridge. Again quite unlike oceanic ridge conditions, south of the classical and well known Trodos mountains (MOORES & VINE 1971, VINE & MOORES 1972) and separated by them by a steep fault zone we find the Mammonia area (Paphos) with a classical ophiolitic mélange, which is transgressed by Maestrichtian marls. This area was studied in detail by LAPIERRE, who observed a pre-ophiolitic volcanism related to Triassic masses and separated this zone from the Trodos ophiolites (ROCCI & LAPIERRE 1969, LAPIERRE & PARROT 1972). Based on personal observations I prefer to regard the Trias with its volcanism as exotic blocks belonging to a Cretaceous Mammonia mélange. Only, and here comes the difficulty, a mélange should not border an oceanic ridge but should be expected at the consuming end of a plate. The last word on the eastern Mediterranean has certainly not yet been said (TURNER 1973).

To the east of the Levant lineament the active border of the northwestern Arabian shield is well exposed. In southeast Turkey, north of the Mardin area, the northwards drift of the shield produced an ophiolitic belt with classical mélange formations. The normal ophiolitic suite is here totally disrupted and mélanges predominate in the overthrust sheets, while erosion of the southwards advancing thrust produced olistostromal ophiolitic sedimentation over the stable plate. Here we observe the juxtaposition of mélange nappes in tectonic contact with secondary ophiolitic olistostromes (Fig. 3). In outcrops and particularly in well sections one sees the intercalation of ophiolitic material into turbidity sediments. These most interesting conditions, known already to KÜNDIG (1956), were described by RIGO DE RIGHI & CORTESINI (1964), without distinguishing ophiolitic nappes and ophiolitic olistostromes. The base of the mélange is again thrust and the thrust plane has subsequently been folded. The mélange top is normally transgressed by Eocene, but in the higher ranges it was covered by the crystalline Bitlis thrust. A coherent ultrabasic thrust sheet is not developed and was probably sheared off by the higher crystalline thrust. Much of this material is now found in the olistostromes of the foreland (*Map Erzurum* with explanatory notes, 1963, Mad. Tetkik Arama Enst.).

This frontal ophiolite belt is not related to the famous "Ankara Mélange" of BAILEY & MCCALLIEN (1950, 1953). The latter occurs in a complicated, often steeply bordered, but mostly flat lying sheet and may have originated from the North-Anatolian fault zone. The presence of widespread and well exposed mélange zones along this important tectonic disturbance has been overlooked by most previous writers whose interest centered on the recent earthquake problems and possible strike slip movements. No convincing proof exists that along this line horizontal shifts of

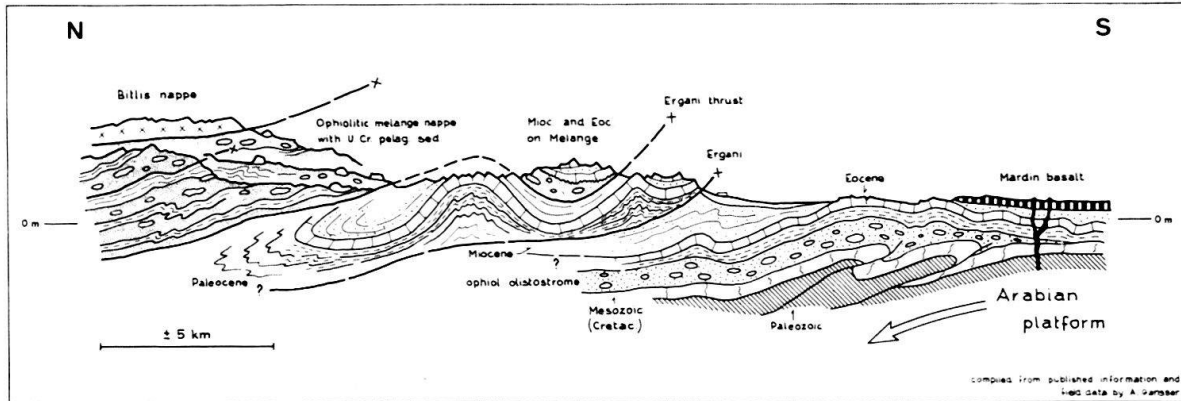


Fig. 3. Ophiolitic mélangé nappe and ophiolitic olistostrome in southeast Turkey.

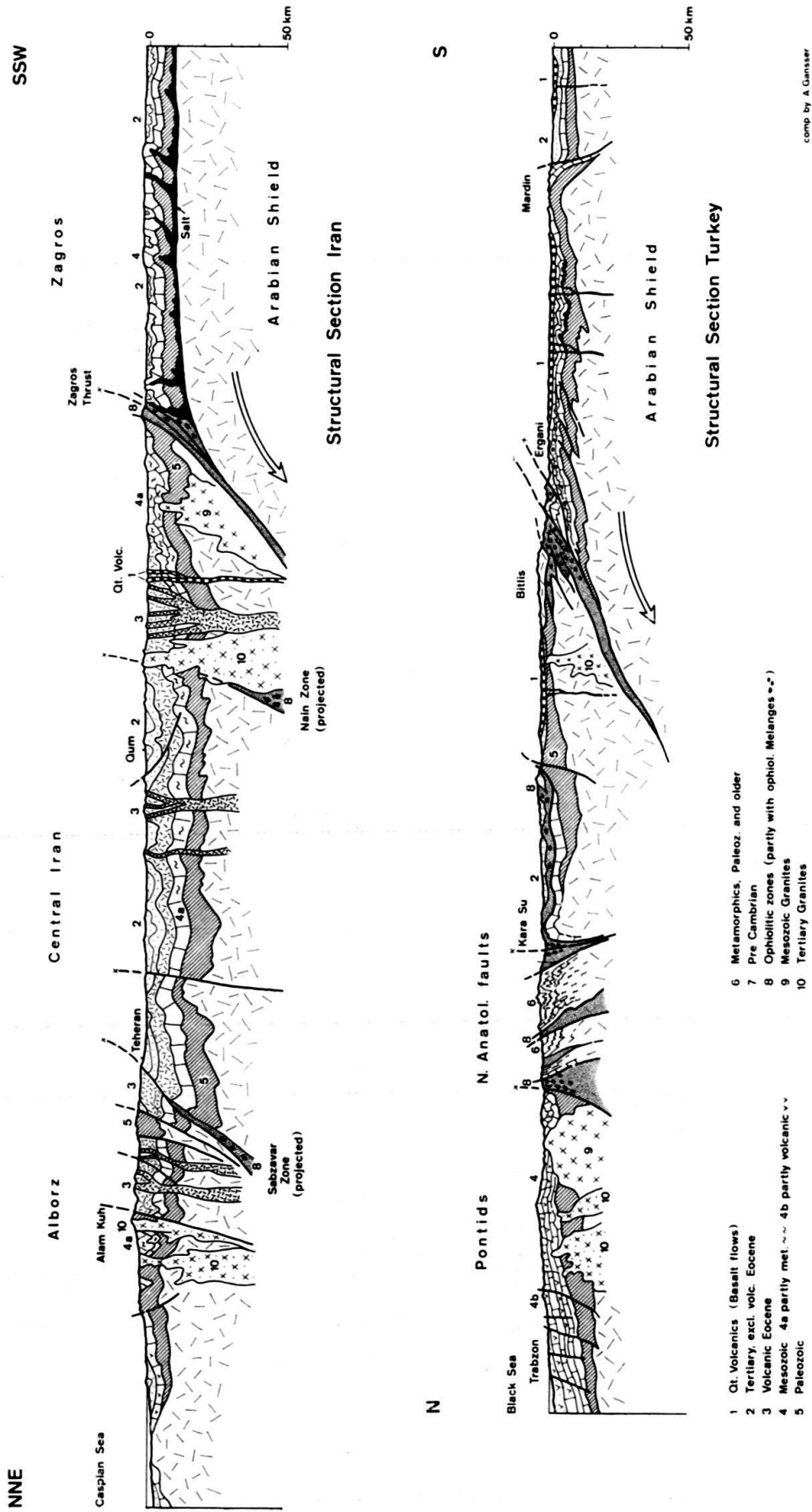
several 100 km accumulated (PAVONI 1961, AMBRASEYS & TCHALENKO 1969, NOWROOZI 1971, 1972). The presence of ophiolitic mélangé suggests a rather large north-south compression which was active in pre-Eocene times along microcontinental margins, with obduction of ophiolitic material, of which the Ankara mélangé may be a witness. In the more eastern sections of the North-Anatolian "fault zones" larger masses of serpentinized ultrabasics together with the mélangé zones do occur (Fig. 4).

c) The Iranian and Afghan mélanges

They occur, similar to those of Anatolia, in two tectonically separate areas. While in Turkey the northern continuation of the western Arabian edge interferes as the Levant lineament, in Iran the eastern edge of the shield, the Oman range, interferes with its northern continuation, the still disputed *Oman line*. First propagated by FURON (1941) and later stressed by GANSSER (1955), estimates of its importance have fluctuated (STÖCKLIN 1968). Now, in connection with various plate boundaries, it has again aroused considerable interest (CRAWFORD 1972). This division is most striking if we compare the Zagros fold belt on the west of the Oman line to the Beluchistan ranges east of it. It is marked by a north-south striking fault zone or steep thrust zone with a considerable dextral displacement (GANSSER 1955; FALCON 1967, 1969; STÖCKLIN 1968).

The main north movement of the Arabian shield has been taken up by the *Zagros thrust* (TAKIN 1972). The underthrusting shield and a young (Pliocene) collision have obliterated a larger part of the previously present mélangé rocks which were probably related to the subduction of Africa and Arabia previous to the opening of the Red sea (LAUGHTON 1966, 1970). At least two phases of post-Miocene movements can be recognized, one mainly thrusting and the other, still younger, with strike-slip elements (BRAUD & RICOU 1971) and vertical uplift.

Locally, ophiolitic mélangé formations are still preserved along the western (Kermanshah region, see BRAUD 1970) and the eastern part of the Zagros thrust, the Neyriz area. In this latter area RICOU (1968, 1971) has revived the tectonic window hypothesis of GRAY (1949) by postulating 3 nappes which are piled on the Zagros foreland, all in front of the main Zagros thrust. He distinguishes above the upper Cretaceous foreland sediments a sedimentary nappe (Pichakun) ranging from Trias to



comp. by A. Gansser

Fig. 4. Structural sections: Iran and Turkey.

middle Cretaceous, a *mélange* nappe with exotic blocks of metamorphic composition (marbles, amphibolites and biotite schists), Permian and Triassic limestones, radiolarites and Cretaceous pelagic limestones as well as basic lavas and serpentines, and on top a several km thick thrust-sheet of peridotites with gabbros. All nappes are transgressed by rudist limestones of Campano-Maestrichtian age, followed by Paleogene and Neogene sediments, themselves overridden by the young Zagros thrust (Fig. 5, Fig. 6). The various tectonic phases are well displayed. Here again, one may realize the effect of the Cretaceous drift of the African plus Arabian plate (pre-Maestrichtian Neyriz nappes) and the subsequent Arabian event in post-Miocene time (opening of the Red sea) which is responsible for the younger Zagros thrust. In spite of its pronounced structural complication, the Neyriz area displays a surprising similarity to Oman (a fact also stressed by RICOU 1971). Between the Cretaceous thrust sheets at Kermanshah and Neyriz, younger movements along the Central part of the Zagros thrust caused overriding of the older nappes. Similar conditions are known from the thrust-zone in Irak-Kurdistan between the Turkish and the Iranian ranges. Here amphibolite bodies together with serpentines suggest an incipient metamorphism, which also affected the upper Cretaceous flysch (GANSSEY 1959). *Mélange* zones are not exposed and are again probably overridden or sheared off during the younger movements.

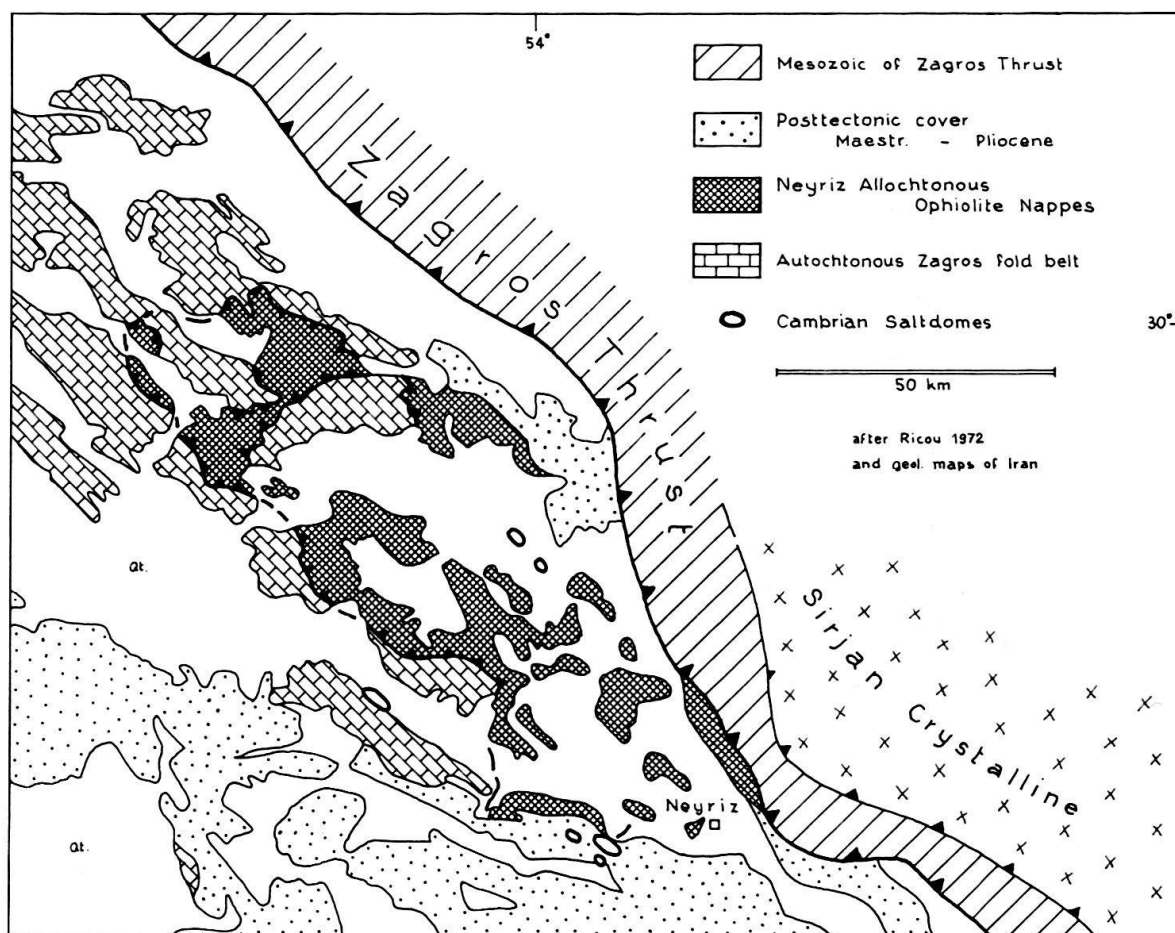


Fig. 5. Geological sketchmap of the Neyriz area.

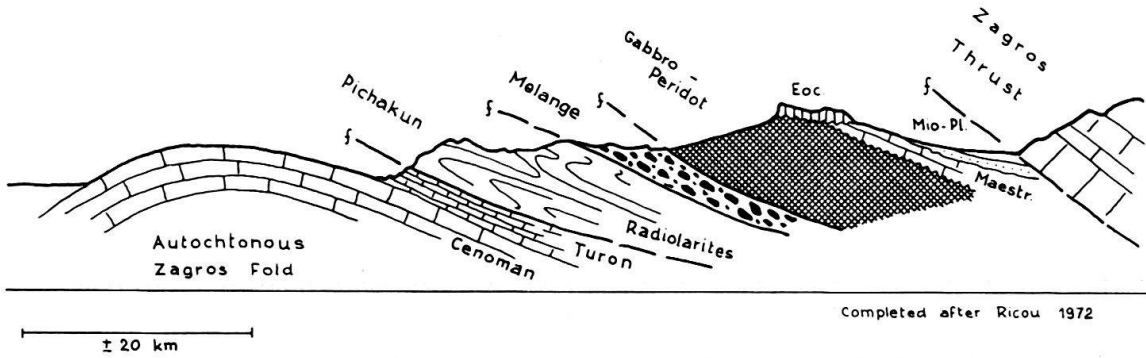


Fig. 6. Schematic section through the Neyriz nappes.

While the Zagros thrust has assimilated most of the north drift of the Arabian shield, in the wide and most complex area of Central Iran certain ophiolite mélangé belts are surprisingly well preserved (Fig. 2). We find the best investigated area in the very center of Iran, in Nain (DAVOUZADEH 1969). Here mélangé belts are present

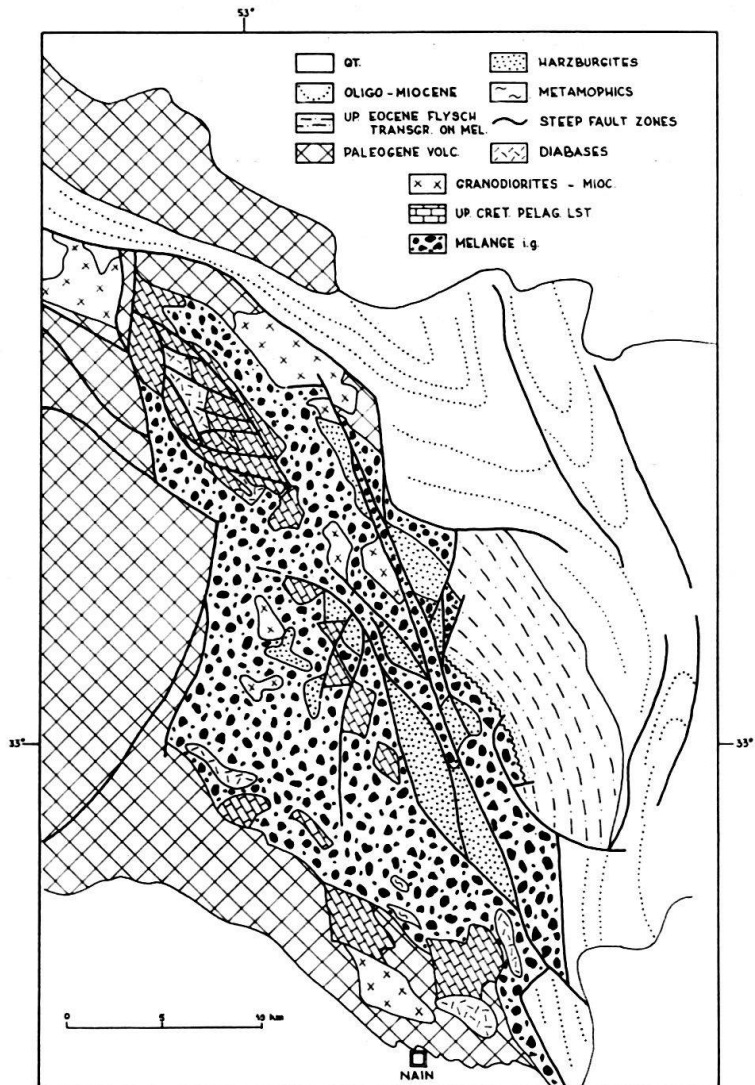


Fig. 7. The ophiolitic mélangé of the Nain area, Central Iran (generalized after DAVOUZADEH 1969).

besides large homogeneous bodies of ultrabasics (Fig. 7). All contacts are steeply thrust, but not overthrust as they are in Neyriz, Oman or the Himalaya. Along a sharp south-east trending fault zone, reactivated in recent time (faulted alluvial fans), the Nain zone trends towards the mélangé area of Neyriz already south of the Zagros thrust zone.

East of the Oman line the dominant geological feature is the *Lut block* (GANSSE 1969, STÖCKLIN et al. 1972), a classical microcontinent surrounded on its north, east and south side by more or less tectonized ophiolitic mélangé zones. The northern area is at present being investigated by the University of Mashad, and mélangé zones, mapped in detail, have provided a wealth of data (Davoudzadeh, personal information). Pink Globotruncana limestones and large patches of radiolarites are widely distributed, the latter apparently concentrated in the southern part of two belts (just north of the Doruneh fault zone). Rodingites in all possible stages of development are very frequent in the ultrabasic bodies (mostly harzburgites) while diabbases are rather rare and top some of the higher mountains.

On the eastern edge of the Lut block ophiolitic mélangés form narrow bands which are limited by strike slip faults (FREUND 1970, GANSSE 1971, STÖCKLIN et al. 1972). They enter the northeastern part of the block as steep slices and may be associated with the large earthquakes within the northern Lut block (GANSSE 1969, AMBRASEYS & TCHALENKO 1969, NOWROOZI 1972). In spite of the strong tectonization within those slices, large masses of pillow lavas are locally preserved and show surprisingly little deformation.

The mélangé zones increase towards the southeast of the Lut block within upper Cretaceous flysch. In the middle of one of those larger mélangé areas erupted the still semi-active Taftan volcano (GANSSE 1971). This volcano, together with the Bazman volcanics, belongs to an east-west aligned volcanic belt separating the main Lut block from the Djaz Murian basin in the south. Along the southern border of this stable mass occur some of the largest ophiolitic belts in Iran which extend into the Makran region north of the Gulf of Oman. Unfortunately these remote areas are little known, and my information is mainly based on personal reconnaissance surveys (Fig. 8). Somewhat similar to the Nain region, though on a larger scale, massive basic (gabbro and diabase) and ultrabasic (serpentinized harzburgite) bodies are sharply separated from extensive mélangé zones. The contacts are mostly steep,

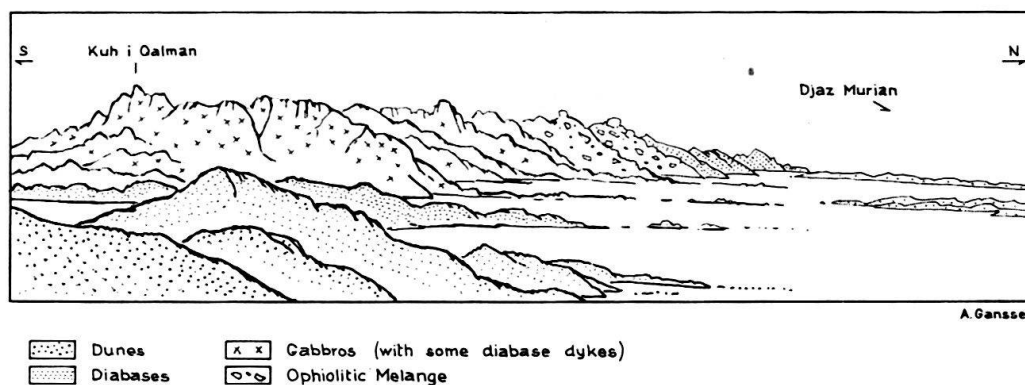


Fig. 8. The little known ophiolite belt south of Djaz Murian basin (view to west).

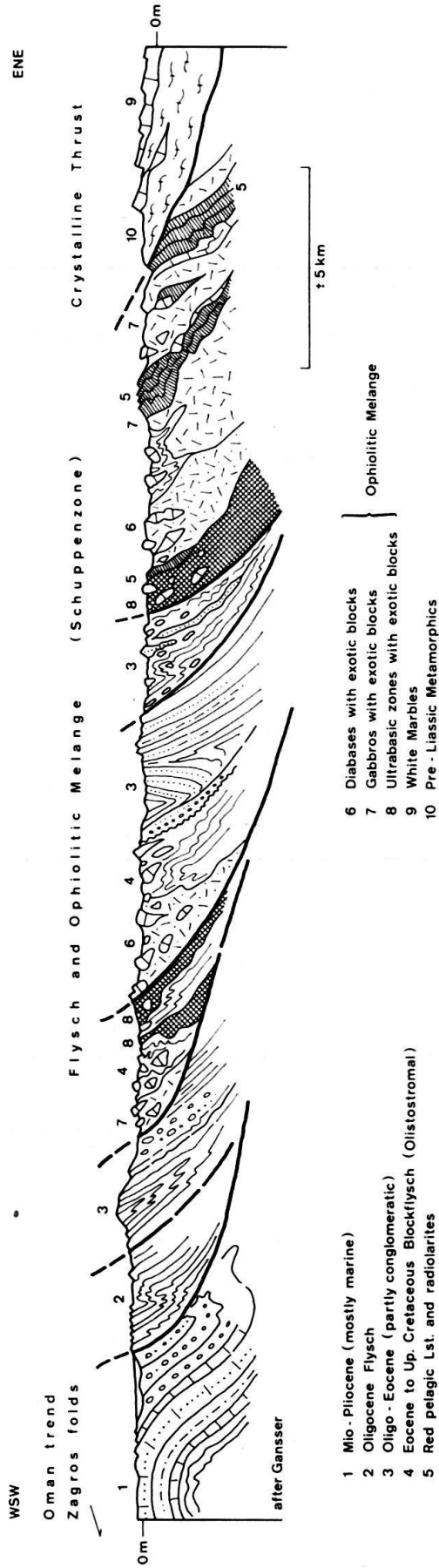


Fig. 9. Flysch/mélange section : north Minab, southeast Iran.

except for the western part, where one observes westwards thrusting towards the eastern Zagros (Oman line) (Fig. 9).

This section is of considerable interest, since it displays a crystalline thrust sheet in the east which forms the highest unit. All tectonic contacts are steep at the surface but seem to flatten out at depth – a pattern of regional importance in this area. The crystalline thrust sheet consists of diaphoretic chlorite-sericite schists and chloritic hornblende gneisses with intercalated small bands of gray marbles. They are topped by conspicuously white, sugary marbles, which are widespread as enclosures within the underlying mélange formations. In the Sargaz area the crystalline rocks are transgressed by flyschoid sediments which contain Liassic ammonites (unpublished report by Harrison 1936). In analogy to the Bitlis thrust sheet (Fig. 3) in southeastern Turkey, the pre-Liassic carbonates could also be Permian and not Precambrian as generally accepted. The lithological and even structural similarities are striking.

Within the mélange thrust sheets we find masses of diallage peridotites, serpentines with more or less developed ophicarbonates, diallage gabbros crisscrossed by gabbro-pegmatite dykes, various diabases and rarely pillow lavas. Apart from the ophiolitic components occur some reddish amygdaloid porphyries of a probable pre-ophiolitic age and sediments such as radiolarites, pink pelagic limestones, siliceous limestones together with white marbles, chlorite schists, epidote quartzites and hornblende-chlorite-schists of the type reminiscent of the crystalline thrust sheet. As youngest component occur *Globotruncana*-bearing pinkish argillaceous limestones.

All these blocks are again incorporated as olistostromal zones within the Eocene and lower Oligocene flysch. This fact is typical in the whole Beluchistan area and reminds again the conditions described in southeastern Turkey, only with more structural complications. In such areas the clear distinction between ophiolitic mélange formations and ophiolitic olistostromes is often difficult, and only a careful analysis of the youngest ages of matrix and blocks and of the structural relations can solve this problem. Most of these flysch sections show a highly compressed isoclinal folding. A younger east/west component with horizontal displacements is added to the structural complications. The flysch is transgressed unconformably by strongly deltaic clastic sediments which initiate the several kilometer thick Mio-Pliocene Makran group. The latter extends southeastwards to the Makran coast and beyond, and covers with its gentle folds a structurally highly complicated subsurface.

Since the Makran region is situated east of the Oman line, the effect of the underthrusting Arabian shield diminishes. In the gap between the Arabian and the Indian plate occur microcontinents such as the Lut block and the Sistan-Helmand blocks of central Afghanistan. A differential movement between these small but coherent masses seems evident and is well displayed around the Lut block with its well outlined fault zones. Along its eastern border they strongly affect the ophiolitic zones by shearing larger ultrabasic masses from the more mobile ophiolitic mélange formations. We again find similar movements in the major fault zones limiting central Afghanistan such as the Herat fault in the north and the Chaman fault in the southeast. Both these fault zones merge towards the east-northeast into the Kabul area and continue along the Panj Shir valley into the Hindukush. Between this triangular fault system all other structures are more and more compressed towards northeast, a narrowing effect, related to the stronger northwards drift of the northwestern Indian

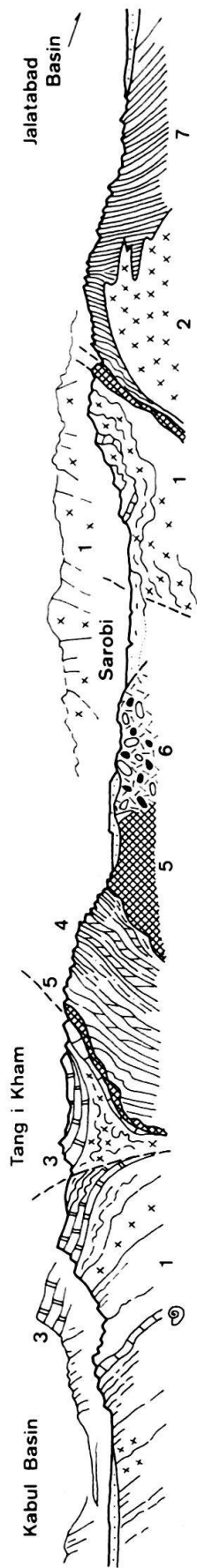
plate, as compared to the Arabian shield. The differential movement between the Arabian and Indian plates is mostly taken up by the large Chaman fault which separates two surprisingly different areas. While west of the fault zone the basement is covered by a complete Paleozoic and Mesozoic conformal section with some granitic intrusions, the eastern side displays large sedimentary gaps, a marked ophiolitic belt and a flysch facies of the uppermost Cretaceous and the Paleogene (DE LAPPARENT 1972). It is along this ophiolitic belt, south and southeast of Kabul, that well developed ophiolitic *mélange* zones are exposed, in sharp contact with the ultrabasic masses of the Logan Valley and along the Kabul river. They are transgressed by the basal conglomerates of the Eocene flysch, which locally contain ophiolitic olistostromes. These *mélange* formations along the Chaman fault and its secondary branches, well displayed in the Altimur region (MENNESSIER 1972), stress the importance of this structural trend and underline the striking facies changes related to it (Fig. 10).

The Quarternary volcanism, widespread in the west, disappears northeastwards, and its last occurrence was only recently discovered in the Dasht i Nawar region of central Afghanistan by BORDET (1972). No Quarternary or Recent volcanism is known within the orogenic belt around the northwards drifting Indian plate.

d) The Himalayan mélanges

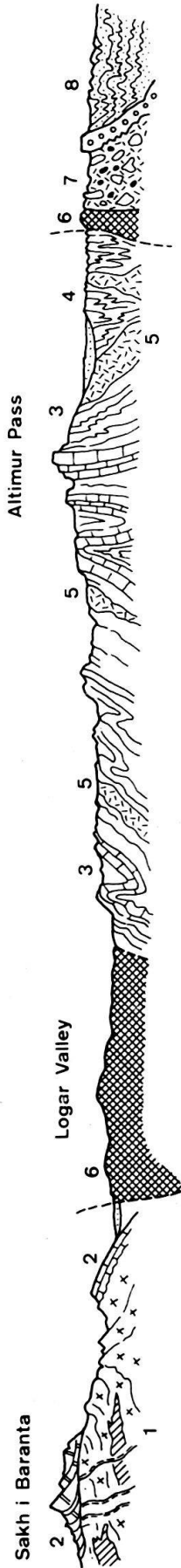
The Chaman fault trend as well as the more eastern Quetta line, which separates the Indian platform sediments from the ophiolitic Beluchistan trend (GANSSEER 1966), can be followed through the western Himalayan syntaxis into the Indus zone of the northern Himalayas, where the relation of ophiolitic *mélange* nappes to one of the best preserved plate boundaries is excellently exposed. Unfortunately this area is still very little known. We have now returned to our starting point, where 82 years ago the famous trio of geologists of the Indian Geological Survey were staring at a then not yet recognized ophiolitic *mélange* front.

Along the Indus zone, north of the Himalaya main range, we know so far three areas where the ophiolitic belt, which outlines the important suture line (plate boundary), has been studied. From west to east we distinguish the wider Ladak zone with the Dras volcanic belt (DE TERRA 1935, WADIA 1937), the ophiolites of the Rupshu area (BERTHELSEN 1951, 1953) and the Kiogar Kailas area (VON KRAFFT 1902, HEIM & GANSSEER 1939, GANSSEER 1964). It is in the latter region where we find, apart from the steep "root zone", a large extension of ophiolitic *mélange* nappes with a visible thrusting (or gliding) of over 80 km (Fig. 11). As far as we know this remote but highly interesting area has not been reinvestigated lately – at least no newly published information is available. However, reappraisals of previous findings in the light of modern global tectonics, paleomagnetic informations and comparisons with the well outlined ophiolitic *mélange* zones of the Middle East stress the intimate relations of the Himalayan *mélanges* to the zone of collision and subsequent obduction along the Indian and Eurasian (Tibetan) plate boundary (GANSSEER 1966, 1973, DEWEY & BIRD 1970, CRAWFORD 1972, POWELL & CONAGHAN 1973, ATHAVALE 1973, CHANG CHEN-FA & ZENG SHI-LANG 1973). The divergence of opinion in the modern publications on this subject is understandable, since only a very few of these authors have seen the facts in the field.



Kabul River Section, Centr. Afghanistan

- 1 Gn. Sch. + Gr. Gn. Pre E - Pal.
- 2 Bi Granite (Mesoz.)
- 3 Trias - Lias
- 4 Sch. + Radi. (Mesoz.)
- 5 Peridotite ± Serp.
- 6 Ophiol. Melange
- 7 blk. Slates (Mes.?)



Altimur Section, Centr. Afghanistan

- 1 Sch. Gn., Amfib. + Diab. dykes
- 2 Perm - Trias
- 3 Cretaceous Lst. + Sh.
- 4 Cretaceous Flysch
- 5 Diabases + Pillow L.
- 6 Peridotites
- 7 Ophiol. Melange
- 8 E Flysch with basal Cgl.

Fig. 10. Kabul River section and Altimur section (Central Afghanistan).

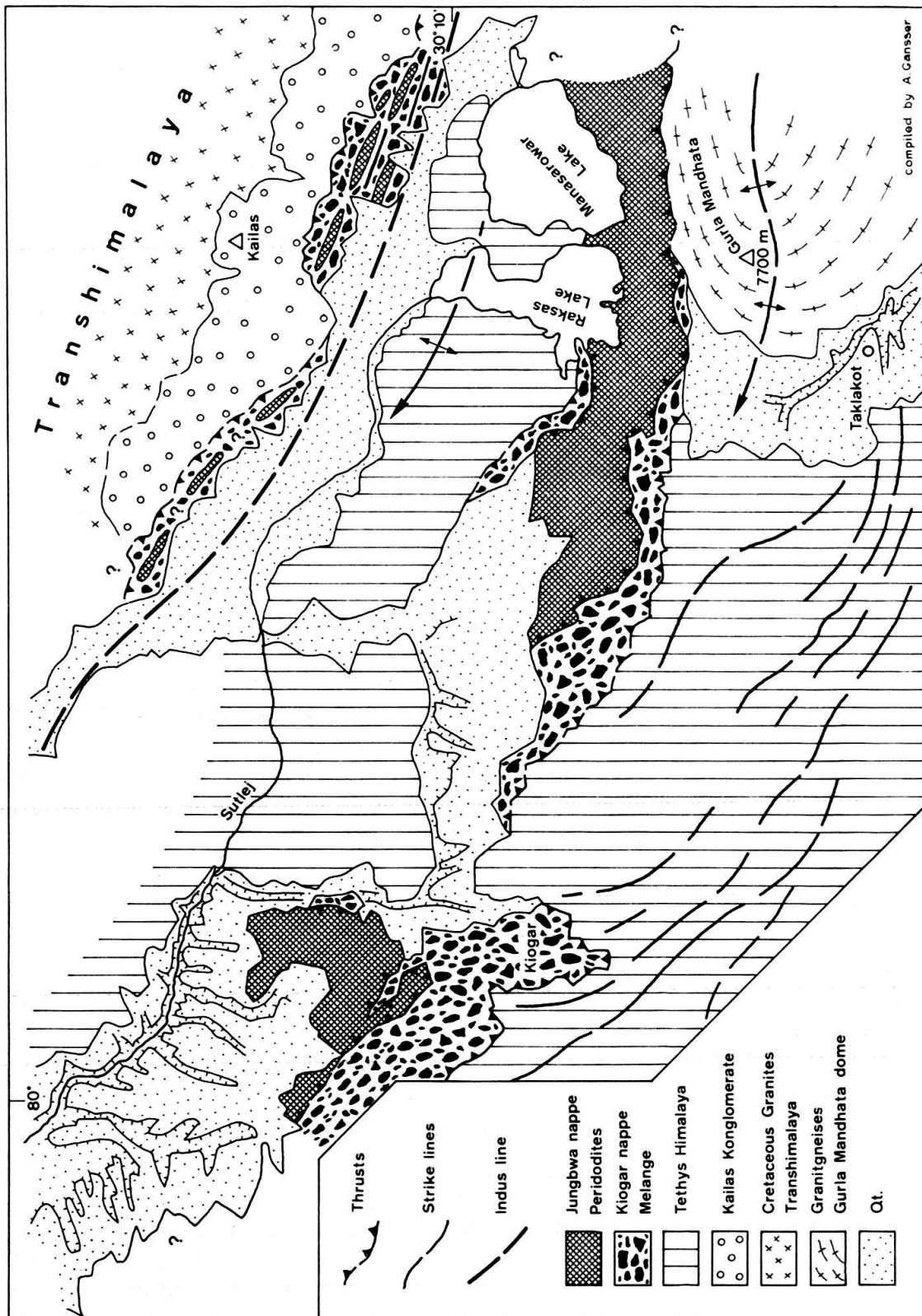


Fig. 11. The ophiolitic nappes in the Northern Central Himalaya (scale appr. 1 : 1 200 000).

Between the Indian/Tibetan border and the Transhimalaya south of the holy Kailas mountain we can recognize three major structural units: 1. *The Tethys Himalayan fold belt*, which in respect to the overlying ophiolitic nappes forms a neo-

autochthonous base. 2. An *ophiolitic mélange nappe*, which, following VON KRAFFT (1902), will be locally called the Kiogar nappe. 3. An *ultrabasic nappe*, which forms the highest structural element of the Himalaya, previously referred to as the Jungbwa unit, more recently as the Jungbwa nappe (GANSSE 1964). Each unit is limited by major thrusts, which again can be complicated by subsequent imbrications (Fig. 12).

The sediments of the *Tethys Himalaya* display a Jura type folding and include the middle Cretaceous Jumal sandstones. Following above the pelagic and ammonite-rich Spiti shales, the Jumal sandstones indicate the beginning of the first orogenic Himalayan phase. The disturbance of the long conformable history of Tethys sedimentation, spanning the time from Eocambrian to the middle Cretaceous, is reflected by the incoming of detrital sediments which lead upwards into a flyschoid facies. These sediments were folded and subsequently sharply overthrust by the Kiogar ophiolitic mélange nappe, which cuts the already existing folds and postdates the Tethys folding phase.

The *Kiogar ophiolitic mélange nappe* exposes one of the best mélange sequences on our globe, well described on its southern margin by VON KRAFFT already in 1902 (Fig. 13). We also find some of the largest single units known, such as the Triassic Kiogar limestone covering as a single "block" an area of 20 km² with a thickness of up to half a km. For a detailed account of this area I refer to HEIM & GANSSE (1939, with a new edition 1974). Of special interest is the fact that the numerous sedimentary blocks display a facies unknown otherwise in normal outcrops in the Himalaya, and they witness a sedimentary basin of oceanic dimensions which has completely disappeared during the collision between the Indian and Tibetan plates. This is particularly true for the Permian, Triassic, Liassic and upper Jurassic blocks, while radiolarites and flysch blocks are not unlike some of the uppermost Cretaceous of the normal Tethyan sediments. Flysch-type sediments as well as highly sheared basic and ultrabasic rocks form the matrix of the mélange.

The most frequent sedimentary inclusions are Permian crinoidal limestones, which contain brachiopods, and various types of Triassic rocks. Amongst the latter huge algal limestone blocks and slabs contrast with pelagic limestones of Hallstätter type. VON KRAFFT discovered a Carnian limestone block from which 40 species of ammonites have been described (DIENER 1912). Curiously enough some of these Triassic blocks are embedded in red and greenish, more or less amygdaloid porphyrites, some even with free quartz, which are strictly related to the Trias and display sometimes intrusive contacts. They can also occur as single blocks within the flysch. It seems most likely that these volcanics are only slightly younger than the Triassic limestones and that they have no relation to the ophiolitic suite. We observe here a certain similarity with the porphyritic rocks related to Triassic limestones in the Mammonia region of southern Cyprus (see p. 486). Unknown in the "normal" Himalayan sediments are blocks of Liassic limestone containing ammonites and resembling the Adneth facies of Austria. Again of a most peculiar and otherwise unknown facies are oolitic limestones imbricated with a Kiogar block containing Calpionellas. This rather unexpected association is of particular interest, apart from the fact that Calpionellas seem to be unknown in the eastern Tethys. The Kiogar Calpionellas may actually represent the easternmost occurrence within the Tethys belt (personal information from Michel Durand-Delga).

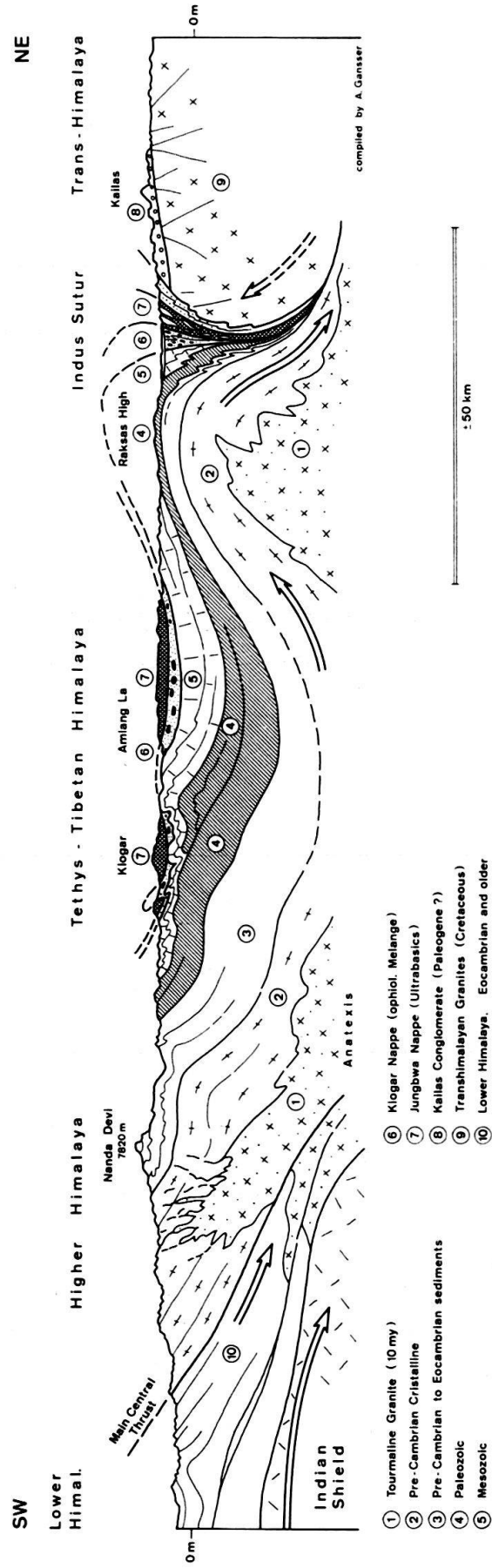


Fig. 12. Structural section: Northern Central Himalaya.

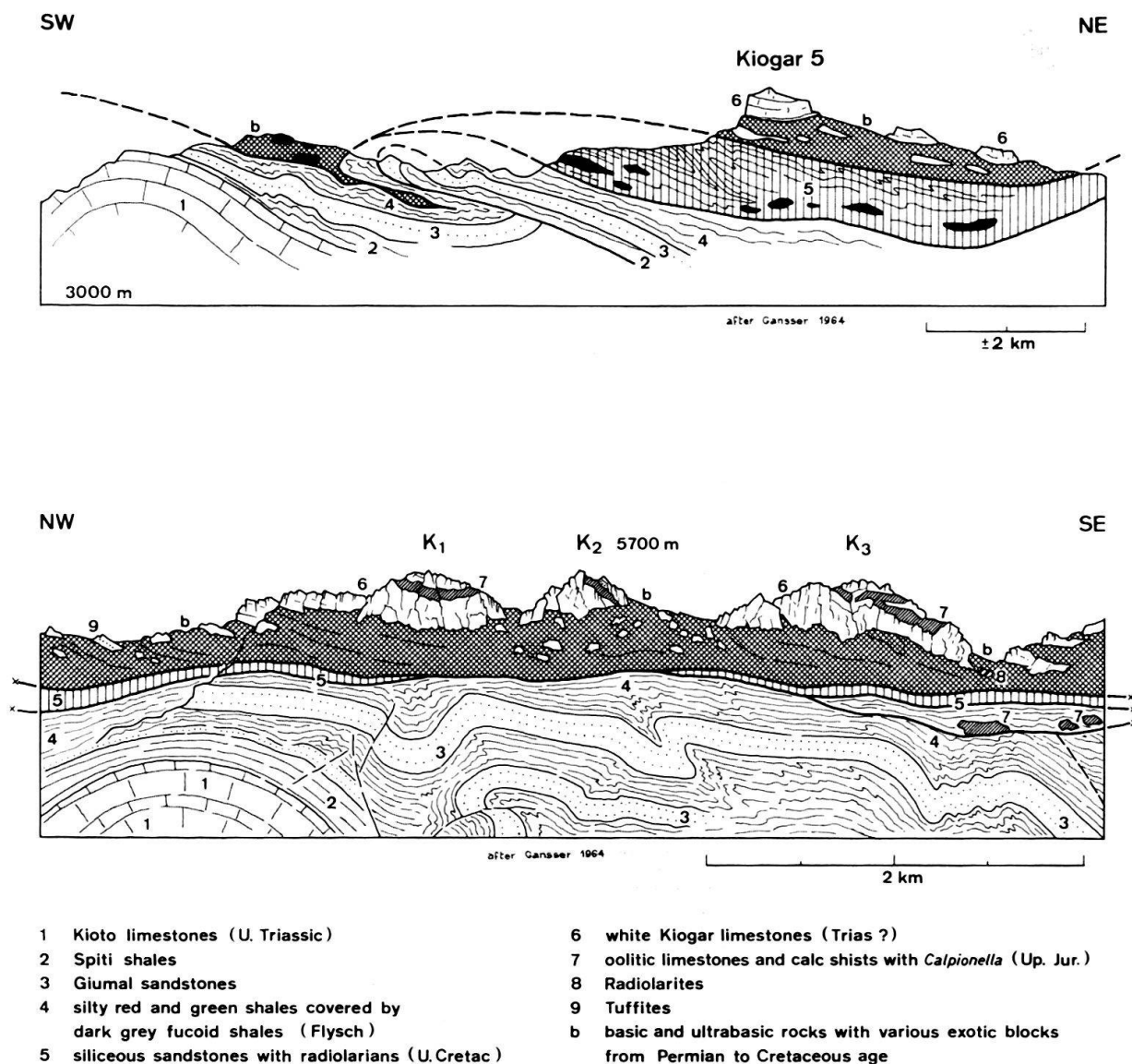


Fig. 13. The ophiolitic Kiogar thrustmass with exotic blocks, Northern Central Himalaya.

Of the younger sediments, radiolarites, siliceous shales and limestones and glauconitic sandstones have been noted. Apart from sediments the *mélange* exposes various types of basic and ultrabasic rocks within the *flysch* or replacing the latter as matrix but again appearing in some areas as blocks. Peridotites, serpentines, often with borders of ophicarbonates and diabase, are a frequent association. To complicate this geological jumble even more, we observe within some *flysch* horizons of the Amlang La region in southern Tibet layered intrusions of fine to medium grained augite monzonites with pigeonitic augite, alkalifeldspar, andesines and biotite. These curious rocks show thermal contacts with *flysch* limestones and form a post-*flysch* intrusion, probably of post-Cretaceous age. It may be younger and not related to the ophiolitic association.

The Kiogar ophiolitic *mélange* nappe is again overthrust by the highest structural unit of the whole Himalaya, the ultrabasic *Jungbwa nappe* (Fig. 14). There seems little

layan syntaxes over 900 km to the area under discussion in the northern Central Himalayas. One of the biggest open questions is the continuation of this major tectonic element to the east. That it continues with the same trend is indicated by the east-west striking topographical features, underlined by the suspiciously straight Tsangpo river system. A few observations corroborate this assumption. HAYDEN (1907) reported from the area south of Shigatse (southern Tibet) numerous basic intrusions in the form of diabases, noritic gabbros and serpentines within metamorphic Jurassic (Cretaceous) calcareous schists. He followed these basic rocks to the large Yamdrok Tso (lake) in the east. WIENERT (1947), in a little known publication, refers to his magnetic measurements during the botanical Schaefer expedition between Sikkim and Lhasa in 1938/39. Most surprising are the sudden large magnetic anomalies along the Tsangpo river (+2600 γ , while just south of it, at Tsetang, the measurements drop to -870 γ). Recently an ultrabasic belt along and paralleling the Tsangpo river was mentioned by Chinese geologists (CHANG CHEN-FA & ZENG SHI-LANG 1973). This information further supports an eastern extension of the ophiolitic belt of the northern Himalaya, the structural aspect of which is well exposed in the ERTS pictures covering this area. It may not take long before ophiolitic mélange formations are recognized also in this remote area, further corroborating the important suture zone related to the collision of the Indian and Eurasian plates.

4. Conclusions

The intimate relations of the ophiolitic mélange to the ophiolitic belts of world-wide distribution show us that most problems adherent to the ophiolites exist for the mélange formations. I stress the recognition of ophiolite belts as originally representing oceanic crust and mantle, a fact of prime importance when interpreting ophiolites in highly tectonized mountain ranges with nappe character (Alps, Himalaya) (DEWEY & BIRD 1970, 1971; MOORES 1970, 1973; GILLULY 1971; ROST 1971; VINE & MOORES 1972; ABBATE et al. 1972; GANSSER 1973; Academy of Science, Moscow 1973, I-III). The consumption of oceanic lithosphere in subduction zones along major mountain ranges is by now well known. While subduction is generally accepted, obduction (AVIAS 1967, COLEMAN 1971, MOORES 1973) brings us the same difficulty as the formation of ultrabasic nappes. Evidently most of the ophiolitic belts are now visible, because they are obducted and not subducted. This statement is particularly applicable to mélange formations, and we may go so far to state that an ophiolitic mélange may be explained through a mechanism related to obduction. A Cordilleran type orogenic belt with the classical subduction of oceanic crust below a continental margin hardly produces mélange formations. They as well as the ophiolites are missing along 5000 km of Andean subduction (GANSSER 1972). Mélanges are weakly expressed along the northern Andes, but again developed under peculiar conditions along the central west coast of North America (HSÜ 1968, 1971). Substantially different conditions occur at the subduction of continental plates. Obduction of oceanic crust is here the rule, developed into conspicuous thrust-masses of ophiolitic rocks onto slabs of continental crust (COLEMAN 1971). Under these conditions mélange formations are particularly wide-spread, as we have seen in many Asian ophiolitic belts, since our best examples were from the Middle East ranges and the Himalaya,

and recently ophiolitic mélangé formations have been recognized in the Paleozoic Tien-Shan and the Mesozoic of the Lesser Caucasus (USSR Academy of Science's publication 1973). Further obducted ophiolites, where mélangé formations may have been obliterated by thrusting, are reported from Papua (DAVIES 1968, DAVIES & SMITH 1971), though the mode of occurrence has recently been disputed (ROD 1974).

The subduction mechanism of continental plates (shield masses) and the obduction of oceanic crust belonging to basins obliterated during a collision phase is still highly disputed. Flipping of a subduction zone is hardly the answer. The acceptance of the blue schist facies as valid indicator of underthrusting is widely generalized, but to exhume the blue schists from great depth is still a major tectonical problem (COLEMAN 1972). Blue schists mostly occur in mélangé formations as exotic blocks, but they are rather atypical for such formations. It is not the place to enter into these controversies, but we may stress the fact that obducted mélangé formations are mostly related to underthrust continental slabs which do not sink to greater depth but flatten out at approximately 40–60 km. Earthquake centers seem to confirm this in many places (COLEMAN 1971; NOWROOZI 1971, 1972; MOLNAR et al. 1973). This is particularly well documented in the subduction of the Indian plate and its thrust below the Tibetan mass. Earthquakes are widely spaced below the Tibetan plate at depths not exceeding 60 km. Below the Himalaya the calculated focal mechanism is consistent with thrusting along a plane dipping gently to the north (FITCH 1970).

The subduction of the Indian plate, now reflected in the Indus suture line, produced one of the best ophiolitic mélangé formations known on our globe. We can only hope that this challenging area will receive in the future the intense geological investigation it deserves, after the first steps in this direction had been taken by VON KRAFFT 80 years ago.

Acknowledgments

I thank Alan G. Milnes for valuable suggestions and corrections, Sylvia Spalinger for the preparation of the manuscript and Albert Uhr for completing the drawings.

REFERENCES

- ABBATE, E., BORTOLOTTI, V., & PASSERINI, P. (1972): *Studies on mafic and ultramafic rocks. 2: Paleogeographic and tectonic considerations on the ultramafic belts in the Mediterranean area*. Boll. Soc. geol. ital. 91, 239–282.
- (1973): *Major structural events related to ophiolites of the Tethys belt*. International Symposium on Ophiolites in the Earth's Crust, Moscow 1973. Centro Studi Geologia Appennino in rapporto alle Geosinclinali Mediterranee. Cons. naz. Ric. 31, 1–43 (preprint).
- ABDEL-GAWAD, M. (1971): *Wrench movements in the Baluchistan Arc and relation to Himalayan–Indian Ocean tectonics*. Bull. geol. Soc. Amer. 82, 1235–1250.
- Academia Sinica, Laboratory of Isotopic Geology, Kweiyang Institute of Geochemistry (1973): *Isotopic dating of the metamorphic rocks from the Mt. Jolmo Lungma Area, China*. Scientia sinica 16/3, 385–395.
- Academy of Sciences of the USSR, Geological Institute (1973): *Developmental stages of Folded Belts and the problem of Ophiolites (Part I–III)*. Moscow.
- ALLEMANN, F., & PETERS, T. (1972): *The Ophiolite–Radiolarite Belt of the North-Oman Mountains*. Eclogae geol. Helv. 65/3, 657–697.
- AMBRASEYS, N. N. (1970): *Some characteristic features of the Anatolian fault zone*. Tectonophysics 9, 143–165.

- AMBRASEYS, N., & TCHALENKO, J. (1969): *The Dasht-e-Bajaz, Iran, earthquake of August 1968*. Bull. seismol. Soc. Amer. 59, 1751–1792.
- (1972): *Seismotectonic Aspects of the Gediz, Turkey, Earthquake of March 1970*. Geophys. J. r. astron. Soc. 30, 229–252.
- ATHAVALA, R. N. (1973): *Inferences from recent Indian palaeomagnetic results about the northern margin of the Indian Plate and the tectonic evolution of the Himalayas*. Nat. geophys. Res. Inst. Hyderabad, India (preprint).
- ATHAVALA, R. N., HANSRAJ, A., & VERMA, R. K. (1972): *Palaeomagnetism and age of Bhandar and Rewa sandstones from India*. Geophys. J. r. astron. Soc. 28, 499–509.
- AVIAS, J. V. (1967): *Overthrust structure of the main ultrabasic New Caledonian massives*. Tectonophysics 4, 531–541.
- BAILEY, E. B. (1944): *Mountains that have travelled over volcanoes*. Nature (London) 154, 752–756.
- BAILEY, E. B., & MCCALLIEN, W. J. (1950): *The Ankara Mélange and the Anatolian Thrust*. Nature (London) 166, 938–943, and Min. Res. Explor. Inst. Turkey 40, 17–22.
- (1953): *Serpentine lavas, the Ankara Mélange and the Anatolian Thrust*. Trans. r. Soc. Edinburgh 62/2, 403–442.
- BERTHELSEN, A. (1951): *A geological section through the Himalayas. A preliminary report*. Medd. dansk geol. Foren. 12, 102–104.
- (1953): *On the Geology of the Rupshu District N.W. Himalaya*. Medd. dansk geol. Foren. 12/3, 350–414.
- BIQ CHINGCHANG (1971): *Comparison of Mélange tectonics in Taiwan and in some other mountain belts*. Petroleum Geol. Taiwan 9, 79–106.
- BIRD, J. M., & DEWEY, J. F. (1970): *Lithospheric Plate-Continental margin tectonics and the evolution of Appalachian orogeny*. Bull. geol. Soc. Amer. 81, 1031–1060.
- BLUMENTHAL, M. (1948): *Un aperçu de la géologie des chaînes nordanatoliennes entre l'Ova de Bolu et le Kizilirmak inferieur*. Publ. Inst. Etud. Rech. min. Turquie (B) 13.
- BOGDANOFF, A. A. (1967): *Colloque sur la Tectonique de la Zone Alpine de l'Iran et de la Turquie*. Congr. géol. int., Comm. Carte géol. Monde, Moscow, p. 1–20.
- BORDET, P. (1972): *Le volcanisme récent du Dacht-e Nawar*. Rev. Géogr. phys. Géol. dyn. 14/4, 427–431.
- BRAUD, J. (1970): *Géologie générale. – Les formations du Zagros dans la région de Kermanshah (Iran) et leurs rapports structuraux*. C. R. Acad. Sci. Paris (D) 271, 1241–1244.
- BRAUD, J., & BRUNN, J. H. (1972): *Présence de quartz-kératophyres et de brèches éruptives dans les roches vertes des unités almpiennes occidentales du Vermion (Grèce)*. C. R. Soc. géol. France 10, 29–30.
- BRAUD, J., & RICOU, L.-E. (1971): *Tectonique. – L'accident du Zagros ou Main Thrust, un charriage et un coulissement*. C. R. Acad. Sci. Paris (D) 272, 203–206.
- BRUNN, J. H. (1959): *La dorsale médio-atlantique et les épanchements ophiolithiques*. C. R. Soc. géol. France 8, 234–235.
- (1973): *Contribution à la discussion sur la mise en place – magmatique ou tectonique – des ophiolites*. Symposium sur les ophiolites dans la croûte terrestre. Moscow, May–June 1973 (preprint).
- CHANG CHENG-FA & ZENG SHI-LANG (1973): *Tectonic features of the Mount Jolmo Lungma region in southern Tibet, China*. Scientia geol. sinica 1, 1–12.
- COLEMAN, R. G. (1963): *Serpentinities, rodingites and tectonic inclusions in Alpine-type mountain chains*. Spec. Pap. geol. Soc. Amer. 73.
- (1971): *Plate tectonic emplacement of upper mantle peridotites along continental edges*. J. geophys. Res. 76/5, 1212–1222.
- (1972): *Blueschist metamorphism and plate tectonics*. 24th int. geol. Congr., Sect. 2: Petrology, p. 19–26.
- (1973): *Ophiolites in the earth's crust: A symposium, field excursions, and cultural exchange in the USSR*. Spec. Rep. Geology, geol. Soc. Amer., p. 51–54.
- CRAWFORD, A. R. (1972): *Iran, continental drift and plate tectonics*. 24th int. geol. Congr., Sect. 3, p. 106–112.
- (in press): *The Indus suture line, the Himalaya, Tibet and Gondwanaland*.
- DASARATHI, N. (1967): *Tectonic-setting of Indus ophiolites*. Upper Mantle Symposium, New Delhi 1964, p. 33–43 (Berlingske Bogtrykkeri, Copenhagen).

- DAVIES, H. L. (1968): *Papuan ultramafic belt*. 23rd int. geol. Congr. Prague 1, 209–220.
- DAVIES, H. L., & SMITH, I. E. (1971): *Geology of Eastern Papua*. Bull. geol. Soc. Amer. 82, 3299–3312.
- DAVOUDZADEH, M. (1969): *Geologie und Petrographie des Gebietes nördlich von Nain, Zentral-Iran*. Mitt. geol. Inst. ETH u. Univ. Zürich.
- DEWEY, J. F., & BIRD, J. M. (1970): *Mountain belts and the new Global tectonics*. J. geophys. Res. 75/14, 2625–2647.
- (1971): *Origin and emplacement of the Ophiolite suite: Appalachian ophiolites in Newfoundland*. J. geophys. Res. 76/14, 3179–3206.
- DIENER, C. (1895): *Ergebnisse einer geologischen Expedition in den Central-Himalaya von Johar, Hundes, und Painkhanda (4. April 1895)*. Denkschr. kais. Akad. Wiss. Wien, math-natw. Classe 62, 533–607.
- (1912): *Trias of the Himalaya*. Mem. geol. Surv. India 36/3, 1–159.
- DIETZ, R. S., & HOLDEN, J. C. (1970): *Reconstruction of Pangaea: Breakup and dispersion of Continents, Permian to present*. J. geophys. Res. 75, 4939–4956.
- DOUGLAS, J. A. (1950): *The Carboniferous and Permian faunas of south Iran and Iranian Baluchistan*. Mem. geol. Surv. India, Palaeontologia indica [n.s.] 22, 7.
- DUCLOS, C. (1964): *Notes of the geology of the Kyrenia range*. Annu. Rep. geol. Surv. Cyprus 1963/64, 57–67.
- ELTER, P., & TREVISAN, L. (1973): *Olistostromes in the tectonic evolution of the Northern Apennines*. In: *Gravity and Tectonics* (John Wiley & Sons, New York), p. 175–188.
- FALCON, N. L. (1967): *The geology of the north-east margin of the Arabian basement shield*. Adv. Sci. (London) 24/119, 31–42.
- (1969): *Problems of the relationship between surface structure and deep displacements illustrated by the Zagros Range. Time and Place in orogeny*. Spec. Publ. geol. Soc. London 3, 9–22.
- FITCH, T. J. (1970): *Earthquake mechanisms in the Himalayan, Burmese and Andaman regions and continental tectonics in Central Asia*. J. geophys. Res. 75, 2699–2709.
- FREUND, R. (1970): *Rotation of strike slip faults in Sistan, Southeast Iran*. J. Geol. 78/2, 188–200.
- FREUND, R., GARFUNKEL, Z., ZAK, I., GOLDBERG, M., WEISSBROD, T., & DERIN, B. (1970): *The shear along the Dead Sea rift*. Phil. Trans. r. Soc. London (A) 267, 107–130.
- FREUND, R., ZAK, I., & GARFUNKEL, Z. (1968): *Age and rate of the sinistral movement along the Dead Sea rift*. Nature (London) 220/5164, 253–255.
- FURON, R. (1941): *Géologie du Plateau Iranien*. Mém. Mus. Hist. nat. Paris 7/2,
- GANSSER, A. (1955): *New aspects of the geology in Central Iran*. Proc. 4th World Petroleum Congr. Rome, Sect. I/A/5, p. 279–300.
- (1959): *Ausseralpine Ophiolithprobleme*. Eclogae geol. Helv. 52/2, 659–680.
- (1964): *Geology of the Himalayas* (Interscience Publ. John Wiley & Sons Ltd. London.)
- (1966): *The Indian Ocean and the Himalayas. A geological interpretation*. Eclogae geol. Helv. 59/2, 831–848.
- (1969): *The large earthquakes of Iran and their geological frame*. Eclogae geol. Helv. 62/2, 443–466.
- (1971): *The Taftan volcano (SE Iran)*. Eclogae geol. Helv. 64/2, 319–334.
- (1973a): *Facts and theories on the Andes*. J. geol. Soc. London 129/2, 93–131.
- (1973b): *Orogene Entwicklung in den Anden, im Himalaya und den Alpen, ein Vergleich*. Eclogae geol. Helv. 66/1, 23–40.
- (in press): *The Himalayan Tethys*.
- GILLULY, J. (1971): *Plate tectonics and magmatic evolution*. Bull. geol. Soc. Amer. 82/9, 2383–2396.
- GLENNIE, K. W., BŒUF, M. G. A., HUGHES CLARKE, M. W., MOODY-STUART, M., PILAAR, W. F. H., & REINHARDT, B. M. (1973): *Late Cretaceous Nappes in Oman Mountains and their geologic evolution*. Bull. amer. Assoc. Petroleum Geol. 57/1, 5–27.
- GLENNIE, K. W., & HUGHES CLARKE, M. W. (1973): *Late Cretaceous Nappes in Oman Mountains and their geologic evolution: Reply*. Bull. amer. Assoc. Petroleum Geol. 57/11, 2287–2290.
- GRACIANSKY, P. C. (in press): *Le problème des coloured mélanges à propos de formations chaotiques associées aux ophiolites de Lycie occidentale (Turquie)*.
- GRAY, K. W. (1949): *A tectonic window in south-western Iran*. Quart. J. geol. Soc. London 105(II)/418, 189–223.
- GREENLY, E. (1919): *The geology of Anglesey*. Mem. geol. Surv. G.B.

- GRIESBACH, C. L. (1891): *Geology of the Central Himalayas*. Mem. geol. Surv. India 23.
- HAMILTON, W. (1969): *Mesozoic California and the underflow of Pacific mantle*. Bull. geol. Soc. Amer. 80, 2409.
- HAYDEN, H. H. (1907): *The Geology of the Provinces of Tsang and Ü in Central Tibet*. Mem. geol. Surv. India 36/2, 122–202.
- HEIM, A., & GANSSER, A. (1939): *Central Himalaya. Geological Observations of the Swiss Expedition 1936*. Denkschr. schweiz. natf. Ges. 73/1 [new edition: Hindustan Publishing Corp. (India), Delhi 1974].
- HINZ, K., & CLOSS, H. (1969): *Auswertung und Ergebnisse der seismischen Messungen und ihre geologische Deutung. Ergebnisse seismischer Untersuchungen im nördlichen Arabischen Meer, Teil III*. Meteor Forschungr. C/2, 9–28.
- HSÜ, K. J. (1968): *Principles of mélanges and their bearing on the Franciscan-Knoxville paradox*. Bull. geol. Soc. Amer. 79, 1063–1074.
- (1971): *Franciscan mélanges as a model for eugeosynclinal sedimentation and underthrusting tectonics*. J. geophys. Res. 76/5, 1162–1170.
 - (1972): *The concept of the geosyncline, yesterday and today*. Trans. Leicester lit. phil. Soc. 66, 26–48.
- Italconsult (1959): *Preliminary report geo-mining survey. Plan organisation of Iran*. Ist. graf. tiberino (Roma).
- JACKSON, E. D., & THAYER, T. P. (1972): *Some criteria for distinguishing between stratiform, concentric and Alpine Peridotite-Gabbro complexes*. 24th int. geol. Congr., Sect. 2, p. 289–296.
- KAY, M. (1972): *Dunnage melange and Lower Paleozoic deformation in northeastern Newfoundland*. 24th int. geol. Congr., Sect. 3, p. 122–133.
- (1973): *Tectonic Evolution of Newfoundland*. In: *Gravity and Tectonics* (Ed. K. A. DE JONG & R. SCHOLTEN; John Wiley Interscience), p. 313–326.
- KRAFFT, A. VON (1902): *Notes on the “Exotic Blocks” of Malla Johar in the Bhot Mahals of Kumaon*. Mem. geol. Surv. India 32/3, 127–185.
- KÜNDIG, E. (1956a): *The position in time and space of the ophiolites with relation to orogenic metamorphism*. Geol. en Mijnb. [n.s.] 18/4, 106–114.
- (1956b): *Geology and ophiolite problems of East-Celebes* (Gedenkboek H. A. Brower). Verh. k. nederl. geol. mijnbouwkd. Genoot. 16, 210–235.
 - (1959): *Eugeosynclines as potential oil habitats*. 5th World Petroleum Congr. New York, Sect. 1, p. 461–479.
- LAPIERRE, H., & PARROT, J.-F. (1972): *Identité géologique des régions de Paphos (Chypre) et du Baër-Bassit (Syrie)*. C.R. Acad. Sci. Paris (D) 274, 1999–2002.
- LAPPARENT, A. F. DE (1972a): *Esquisse géologique de l’Afghanistan*. Rev. Géogr. phys. Géol. dyn. 14/4, 327–344.
- (1972b): *L’Afghanistan et la dérive du Continent indien*. Rev. Géogr. phys. Géol. dyn. 14/4, 449–455.
- LAUGHTON, A. S. (1966): *The birth of an Ocean*. New Scientist, p. 218–220.
- LAUGHTON, A. S., WHITMARSH, R. B., & JONES, M. T. (1970): *The evolution of the Gulf of Aden*. Phil. Trans. r. Soc. London (A) 267, 227–266.
- LEES, G. M. (1928): *The geology and tectonics of Oman and of parts of southeastern Arabia*. Quart. J. geol. Soc. London 84/336, 585–670.
- LEMOINE, M. (1973): *Les Ophiolites des Alpes et la Tectonique des Plaques*. Symposium “Ophiolites in the Earth’s Crust”, Moscow 1973 (preprint).
- LOCKWOOD, J. P. (1971): *Sedimentary and gravity-slide emplacement of Serpentinite*. Bull. geol. Soc. Amer. 82, 919–936.
- (1972): *Possible Mechanisms for the Emplacement of Alpine-Type Serpentinite*. Mem. geol. Soc. Amer. 132, 273–287.
- Maden Tetkik ve Arama Enstitüsü Yayınlarından (1963): *Explanatory text of the Geological Map of Turkey 1:500000: Erzurum*. Ankara.
- MAXWELL, J. C. (1969): *“Alpine” mafic and ultramafic rocks. – The ophiolite suite: a contribution to the discussion of the paper “The origin of ultramafic and ultrabasic rocks” by P. J. Wyllie*. Tectonophysics 7/5–6, 489–494.

- MENNESSIER, G. (1970): *Découverte du Turonien et de l'Albo-Aptien au sein de la série schisteuse à ophiolites de la partie centrale de la chaîne d'Altimour, Afghanistan Oriental*. C.R. Acad. Sci. (Paris) 270, 1427.
- (1972): *Géologie de la chaîne d'Altimour*. Rev. Géogr. phys. Géol. dyn. 14/4, 345–355.
- MIASHIRO, A. (1966): *Some aspects of peridotite and serpentinite in orogenic belts*. Jap. J. Geol. Geogr. 37/1.
- MOLNAR, P., FITCH, T. J., & WU, F. T. (1973): *Fault plane solutions of shallow earthquakes and contemporary tectonics in Asia*. Earth and planet. Sci. Lett. 19, 101–112.
- MOORES, E. M. (1970): *Ultramafics and orogeny, with models for the U.S. Cordillera and the Tethys*. Nature (London) 228, 837–842.
- (1973a): *Geotectonic significance of ultramafic rocks*. Earth-Sci. Rev. 9, 241–258.
- (1973b): *Plate tectonic significance of Alpine peridotite types*. Earth-Sci. Rev. 9/2, 963–975.
- MOORES, E. M., & VINE, F. J. (1971): *The Troodos massif, Cyprus and other ophiolites as oceanic crust: evaluation and implications*. Phil. Trans. r. Soc. London (A) 268, 443–466.
- MORTON, D. M. (1959): *The geology of Oman*. 5th World Petroleum Congr., Sect. 1, 14, 1–14.
- MU AN-TZE, WEN SHIH-HSUAN, WANG YI-KANG, CHANG PING-KAO & YIN CHI-HSIANG (1973): *Stratigraphy of the Mount Jolmo Lungma region in Southern Tibet, China*. Scientia sinica 16/1, 96–111.
- NOWROOZI, A. A. (1971): *Seismo-tectonics of the Persian Plateau, Eastern Turkey, Caucasus, and Hindu-Kush regions*. Bull. seismol. Soc. Amer. 61/2, 317–341.
- (1972): *Focal mechanism of earthquakes in Persia, Turkey, West Pakistan, and Afghanistan and Plate tectonics of the Middle East*. Bull. seismol. Soc. Amer. 62/3, 823–850.
- ODELL, N. E. (1967): *Geology of the Himalaya(s). Essay Review*. Geol. Mag. 104/1, 86–91.
- PASSERINI, P. (1965): *Rapporti fra le ofioliti e le formazioni sedimentarie fra Piacenza e il Mare Tirreno*. Boll. Soc. geol. ital. 84/5.
- PAVONI, N. (1961): *Die Nordanatolische Horizontalverschiebung*. Geol. Rdsch. 51, 122–139.
- Penrose Field Conference (1972): *Ophiolites*. Geotimes 17/12, 24–25.
- PETERS, T.J. (1969): *Rocks of the alpine ophiolitic suite*. Tectonophysics, spec. Issue 7, 507–509.
- POWELL, C. MCA., CONAGHAN, P. J. (1973a): *Polyphase deformation in phanerozoic rocks of the Central Himalayan Gneiss, Northwest India*. J. Geol. 81/2, 127–143.
- (1973b): *Plate tectonics and the Himalayas*. Earth and planet. Sci. Lett. 20, 1–12.
- PUSHCHAROVSKY, YU. M. (1972): *Tectonics of continental margins of the Pacific Ocean*. 24th int. geol. Congr., Sect. 8, 53–57.
- QUENNEL, A. M. (1958): *The structural and geomorphic evolution of the Dead Sea rift*. Quart. J. geol. Soc. London 114, 1–24.
- QURESHY, M. N. (1969): *Thickening of a basalt layer as a possible cause for the uplift of the Himalayas – a suggestion based on gravity data*. Tectonophysics 7/2, 137–157.
- REINHARDT, B. M. (1969): *On the genesis and emplacement of Ophiolites in the Oman Mountains geosyncline*. Schweiz. mineral. petrogr. Mitt. 49/1, 1–30.
- RICOU, L.-E. (1968): *Une coupe à travers les séries à radiolarites des monts Pichakun (Zagros, Iran)*. Bull. Soc. géol. France (7) 10, 478–485.
- (1971): *Le croissant ophiolitique péri-arabe, une ceinture de nappes mises en place au Crétacé supérieur*. Rev. Géogr. phys. Géol. dyn. (2) 13/4, 327–350.
- RIGO DE RIGHI, M., & CORTESINI, A. (1964): *Gravity tectonics in foothills structure belt of southeast Turkey*. Bull. amer. Assoc. Petroleum Geol. 48/12, 1911–1937.
- ROCCI, G., & LAPIERRE, H. (1969): *Etude comparative des diverses manifestations du volcanisme pré-orogénique au sud de Chypre*. Schweiz. mineral. petrogr. Mitt. 49/1, 31–46.
- ROD, E. (1974): *Geology of Eastern Papua: Discussion*. Bull. geol. Soc. Amer. 85, 653–658.
- ROST, F. (1971): *Die alpinotypen Ultramafitite und ihre Bedeutung für den Tiefgang der alpinen Orogenese*. Verh. geol. Bundesanst. (Wien) 2, 266–286.
- SCHROEDER, J. W. (1944): *Essai sur la structure de l'Iran*. Eclogae geol. Helv. 37/1, 37–81.
- STEINMANN, G. (1905): *Geologische Beobachtungen in den Alpen*. Ber. natf. Ges. Freiburg 16.
- (1927): *Die ophiolitischen Zonen in den mediterranen Kettengebirgen*. 14^e Congr. Géol., sect. Espagne, p. 637–668.
- STÖCKLIN, J. (1968): *Structural history and tectonics of Iran: a review*. Bull. amer. Assoc. Petroleum Geol. 52/7, 1229–1258.

- STÖCKLIN, J., EFTEKHAR-NEZHAD, J., & HUSHMAND-ZADEH, A. (1972): *Central Lut reconnaissance, East Iran*. Rep. geol. Surv. Iran 22, 1–62.
- STRACHEY, R. (1851): *On the Geology of Part of the Himalaya Mountains and Tibet*. Quart. J. geol. Soc. London 7/1, 292–330.
- SUESS, E. (1901): *Das Antlitz der Erde* (Bd. 3/I). Tempsky, Prag–Wien; Freytag, Leipzig.
- (1909): *Das Antlitz der Erde* (Bd. 3/II). Tempsky, Wien; Freytag, Leipzig.
- TAKIN, M. (1972): *Iranian geology and continental drift in the Middle East*. Nature (London) 235/5334, 147–150.
- TERRA, H. DE (1935): *Geological studies in the North-west Himalaya between the Kashmir and Indus valleys*. Mem. Connecticut Acad. Arts Sci. 8, 18–76.
- TSCHOPP, R. H. (1967): *The General Geology of Oman*. Proc. 7th World Petroleum Congr. Mexico 2, 231–241.
- TURNER, W. M. (1973): *The Cyprian Gravity Nappe and the Autochthonous Basement of Cyprus*. In: *Gravity and Tectonics* (John Wiley & Sons, New York), p. 287–301.
- VINE, F. J., & MOORES, E. M. (1972): *A model for the gross structure, petrology, and magnetic properties of Oceanic crust*. Mem. geol. Soc. Amer. 132, 195–205.
- VUAGNAT, M. (1964): *Remarques sur la trilogie serpentinites gabbros-diabases dans le bassin de la Méditerranée occidentale*. Geol. Rdsch. 53/1, 336–357.
- WADIA, D. N. (1937): *The Cretaceous volcanic series of Astor-Deosai, Kashmir, and its intrusions*. Rec. geol. Surv. India 72/2, 151–161.
- WELLMAN, H. W. (1966): *Active wrench faults of Iran, Afghanistan and Pakistan*. Geol. Rdsch. 55/3, 716–735.
- WIENERT, K. (1947): *Preliminary report on the magnetic results of a journey to Sikkim and Southern Tibet*. J. geophys. Res. 52/4, 505–521.
- WILLIAMS, H., & SMYTH, W. R. (1973): *Metamorphic aureoles beneath ophiolite suites and Alpine peridotites: Tectonic implications with West Newfoundland Examples*. Amer. J. Sci. 273, 594–621.
- WILSON, H. H. (1969): *Late Cretaceous Eugeosynclinal Sedimentation, Gravity Tectonics, and Ophiolite Emplacement in Oman Mountains, Southeast Arabia*. Bull. amer. Assoc. Petroleum Geol. 53/3, 626–671.
- WYLLIE, P. J. (1969): *The origin of Ultramafic and Ultrabasic rocks*. Tectonophysics 7/5–6, 437–455.

