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Tectonics of the Caucasus and adjoining regions: implications for the evolution of the Tethys ocean

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Abstract — The evolution of Tethys is analysed on the basis of ophiolitic geology, reconstruction of continental margins, and plate kinematics. The North Anatolian–Minor Caucasian–South Caspian ophiolitic belt is considered to be the major suture of Palaeozoic Tethys, dividing its southern carbonate shelf from the Pontian–Caucasian–Turanian active margin. The Caucasian part of the latter comprises the Transcaucasian island arc, the Great Caucasian small ocean basin, the Great Caucasian island arc and the Precaucasian marginal sea, each characterised by its own magmatic, metamorphic and sedimentary facies association typical of that tectonic environments. The North Anatolian branch of Tethys persisted throughout the Palaeozoic and Mesozoic, whereas eastwards the major oceanic tract shifted south into the Zagros zone.

The Northern frame of Mesotethys comprises the Pontain–Caucasian and Nakhichevan–Iranian island arc systems, divided by the Minor Caucasian basin, a relict of Palaeotethys reduced to a narrow northern branch of the Mesozoic ocean. In the late Cretacaous–Palaeogene, the youngest southwestern branch of Tethys separated Taurus–Anatolia from the Arabian shelf. Its 'old' northern branches were closed in the Palaeogene. Northward subduction in the South Anatolia–Zagros intracontinental basin triggered Neogene calc-alkaline volcanism in the Pontides, Antolia, Caucasus and Iran.

INTRODUCTION

ACCORDING to neomobilistic concepts Tethys is considered to have been an oceanic basin that divided Eurasia from Gondwanaland in the Palaeozoic and Mesozoic. It is assumed that Tethyan oceanic crust was consumed along subduction zones, the remanents of which are preserved within the Alpine–Himalayan belt as extensive ophiolitic suture zones or scattered allochthonous nappes of ophiolites. In the Eastern Mediterranean the major ophiolitic belts are those of Vardar, Northern Anatolia, the Minor Caucasus and the Southern Caspian in the north, and Oman, Zagros and Southern Anatolia in the south. The southern ophiolites are principally of Mesozoic age, but in the northern belt Palaeozoic ophiolitic complexes are locally preserved. Palaeozoic ophiolites also occur in the Great Caucasus, while Mesozoic–Cenozoic mélanges are characteristic of Central Iran. Because the available geological information is incomplete and because different workers approach the problem differently, there are significant contrasts between the numerous palaeotectonic models for the evolution of Tethys and its continental frame. The positions of the main oceanic axes, the characters of the transition between Palaeozoic and Mesozoic Tethys, the structure of oceanic margins during different episodes of its evolution, and the date of initiation and scale of its various branches are still subject to discussion (e.g. Dewey *et al.* 1973, Stöcklin 1974, 1977, Khain 1975, 1977, Adamia 1975, Ricou 1976, Gamkrelidze 1976, Adamia *et al.* 1977, 1978, 1979, Biju-Duval *et al.* 1977, Zonenshain & Savostin 1979).

New data on the age, structure and composition of the Great and Minor Caucasian ophiolites, on the geology of their continental frame and recently aquired palaeomagnetic evidence now allow a more detailed reconstruction of the Palaeozoic and Mesozoic paleogeography of the Caucasian part of Tethys and permit reliable correlations with neighbouring regions.

THE CAUCASUS: STRUCTURE AND CORRELATION WITH ADJACENT PARTS OF THE ALPINE–HIMALAYAN BELT

The Caucasus is situated at the junction of the Turkish and Iranian segments of the Alpine–Himalayan fold belt. In the North it is bordered by the Scythian platform, the Hercynian metamorphic basement of which is overlain by late Hercynian molasse and calc–alkaline and acid volcanics succeeded by Mesozoic–Cenozoic epicontinental–marine, lagoonal and continental deposits (Khain 1977). High-K calc-alkaline volcanics of Middle–Triassic–Early Jurassic age are also locally present.

The Caucasus comprises two major structural domains divided by the Minor Caucasian ophiolitic belt. The northern domain, which is underlain by a Hercynian granite–metamorphic basement belongs to the Eurasiatic biostratigraphic province (Termier & Termier 1974, Enay 1976), and experienced magmatism, metamorphism and deformation throughout the Palaeozoic and the Alpine orogeny. The domain comprises two tectonic units: (a) the Great Caucasian goesyncline and (b) the Transcaucasian median mass. Within the Great Caucasian geosyncline the tightly folded and cleaved flysch sequences of Jurassic–Eocene age transgress the Hercynian basement or are conformable on the thick flyschoid rocks of Middle Palaeozoic–Triassic age. Substantial deep-marine basaltic volcanism is known to have occurred in the Liassic–Bajocian and the Middle Cretaceous. Southwards there follows the Transcaucasian median mass with a Baikalian–Hercynian basement unconformably overlain by discontinuous shallow-marine to continental clastic and carbonate sequences of Mesozoic–Cenozoic age. These include thick calc-alkaline andesites of Jurassic–Early Neocomian, Albian–Late Cretaceous, Palaeogene and Neogene–Quaternary ages. The Adjara–Trialetian and Talysh deep-marine basaltic troughs of Albian–Ecoene age are superimposed on the Transcaucasian median mass (Adamia *et al.* 1974).

The Minor Caucasian ophiolitic belt represents a sublatitudinal narrow zone in which tectonic lenses of ophiolitic mélange occur along the junction between the northern and southern Caucasian domains, and ophiolitic nappes of late Albian–Lower Senonian age rest on the margins of the latter (Knipper 1975), K–Ar dates on different members of the ophiolitic assemblage give a wide range of ages from Early Palaeozoic to late Cretaceous (Bagdassarian & Chibukhchian 1976). Pillow-lava-radiolaritic sequences have been palaeontologically dated as middle Jurassic–Early Neocomian and Cenomanian–Early Senonian (Knipper 1975, Sokolov 1977, Satian 1979). The volcanic rocks of the ophiolitic sequences are highly variable in composition. Along with MORB tholeiites there are low-K basalt–andesites of immature island arc affinities, and widespread alkali basalt–trachyte associations of oceanic island type. All these volcanic rocks alternate with radiolarites, micrites, radiolarite–volcanic breccias, tuffs and hyaloclastites, and blocks and lenses of reefal limestones. Thus they are interpreted as having formed on rapidly growing submarine ranges (Zakariadze *et al.* in press).

The southern structural domain (the Nakhichevan subplatform) is characterised by a Precambrian granite–metamorphic basement overlain by monotonous shelf carbonates of Palaeozoic–Triassic age. The discontinuous Mesozoic–Cenozoic succession of this domain comprises shallow-marine to continental carbonates and calc-alkaline volcanics of Albian–Late Cretaceous, Palaeogene and Neogene–Quaternary ages. Until the end of the Palaeozoic the domain belonged to the Gondwana biostratigraphic province (Termier & Termier 1974, Leven & Scherbovitsh 1978). Its Jurassic fauna is of Eurasiatic aspect, but maintains significant differences from that of the Transcaucasian mass, thus implying a divide between the two domains (Rostovtsev & Azarian 1971).

The Minor Caucasian ophiolitic belt passes westwards into the North Anatolian ophiolitic belt which contains similar structures basalt–radiolarite associations, and was emplaced at the same time. In the east the belt reaches the Soviet–Iranian border near Ordubad before disappearing beneath young volcanics. Only a discontinuous belt of Palaeozoic ophiolites extends along the northern margin of the Alborz (Stöcklin 1974). Individual tectonic zones within the northern Caucasian domain are of limited extent and can be followed to the west. The Transcaucasian median mass is directly linked with the Outer Pontides which display a similar Palaeozoic and Mesozoic history. Further west, the Alpine areas of the Inner Pontides, Istranja and Sredna Gora in Bulgaria may be approximately equivalent to the Transcaucasus in their Alpine history, and are characterised by Precambrian basement rocks. The Great Caucasian geosyncline extended into the mountainous part of the Crimea and, with interruptions further west, into the south-eastern part of the Stara Planina of Bulgaria (Kotel Zone), which is thought to represent an early Alpine geosynclinal trough. Even further west, this structure appears to wedge out between the Stara Planina (a late Alpine shelf zone underlain by Hercynian basement), and the Sredna Gora (a Late Cretaceous andesitic belt, superimposed on the Precambrian basement of the Rhodope massif).

To the east the structural units described above are interrupted by the Caspian basin, east of which the Turan plate and the Kopet-Dag represent an Alpine shelf underlain by Hercynian or late Kimmerian basement comparable with the Scythian subplatform (Stöcklin 1974, 1977). In the south, along the discontinuous line of Palaeozoic ophiolites, the Kopet-Dag adjoins the Alborz, an area with Precambrian basement. Thus, the Pontian–Transcaucasian median mass and the Crimea–Caucasian geosyncline are inferred to wedge out within the Caspian basin.

South of the Minor Caucasian ophiolitic belt the South Armenian–Nakhichevan subplatform exhibits crystalline basement and a Palaeozoic–Triassic history which is similar to that in the Taurus–South Anatolian zone in the west and the Zagros–Alborz zone in the east. But in its Alpine history, which is marked by intense block-faulting, clastic shallow-marine to continental sedimentation, long periods of nondeposition, and considerable, predominantly calc-alkaline magmatism, it differs from the Taurus–Zagros shelf. In this respect the Southern Armenian—Nakhichevan subplatform strongly resembles the Central Iran–Alborz structural domain, and thus it probably represents the western part of that domain.

Thus it is concluded that the Caucasus represents the junction between the marginal parts of two en échelon western and eastern Alpine structural domains which possess contrasted pre-Alpine histories and which maintained considerable individuality until the late Palaeogene, despite Alpine magmatism and deformation in both areas being comparable.

In the north, the Alpine domains are bordered by the southern shelf zone of Eurasia (the Balkan and Scythian platforms and the Kopet-Dag). In the south, the Alpine domains are adjacent to the African–Arabian carbonate platform (Taurus-Central Anatolia and Outer Zagros) from which they are separated by the North-Anatolian–Zagros ophiolitic suture.

PALAEOZOIC TETHYS AND ITS CONTINENTAL FRAME

The main branch of Palaeozoic Tethys in the Eastern Mediterranean appears to have been marked by the North Anatolian–Minor Caucasian–South Caspian ophiolitic suture zone, that divided continental blocks with contrasting Palaeozoic histories and which belonged to different biogeographical provinces (Belov 1968, Stöcklin 1974, 1977, Ricou *et al.* 1975, Adamia 1975, Adamia *et al.* 1977). South of the suture extended the Palaeozoic carbonate shelf of Gondwanaland, while north of it the Palaeozoic active margin of Eurasia was characterised by eugeosynclinal and orogenic facies, and intense Hercynian magmatism, metamorphism and deformation.

Several authors have indicated the presence of Palaeozoic (mainly pre-Middle Carboniferous) ophiolites within the North Anatolian part of the suture zone (e.g. Bingöl 1974, Oezken Dora 1971), but late Palaeozoic–Triassic ophiolitic mélanges have also been described (Fourquin 1975, Brinkmann 1976). In the Minor Caucasian ophiolitic assemblage, Knipper (1975) has indicated that blocks of metabasic rocks, with lenses of schists and marbles, are cut by 108 Ma (K–Ar) plagioclase-granites. Hassanov (1979) has reported Palaeozoic gabbros and spessartites (322 ± 2 Ma) within the serpentinites of the Sevan lake area. Only Palaeozoic (pre-Jurassic) ophiolites are known in the Mahashad and Rasht areas of the south Caspian region (Stöcklin 1977, Majdi 1979).

Palaeomagnetic data for the Nakhichevan region of the Southern Caucasian domain (Asanidze *et al.* 1980) closely resemble those obtained from coeval rocks in Alborz, Central Iran, Oman and Southern Afghanistan (Becker *et al.* 1973, Burk & Füster 1975, Krumsicek 1976, Wensink *et al.* 1978, Wensink 1979), indicating that until the Late Palaeozoic these regions, situated near the northern margin of Gondwanaland, were separated from Eurasia by 2500–3000 km (Fig. 1b). Throughout the

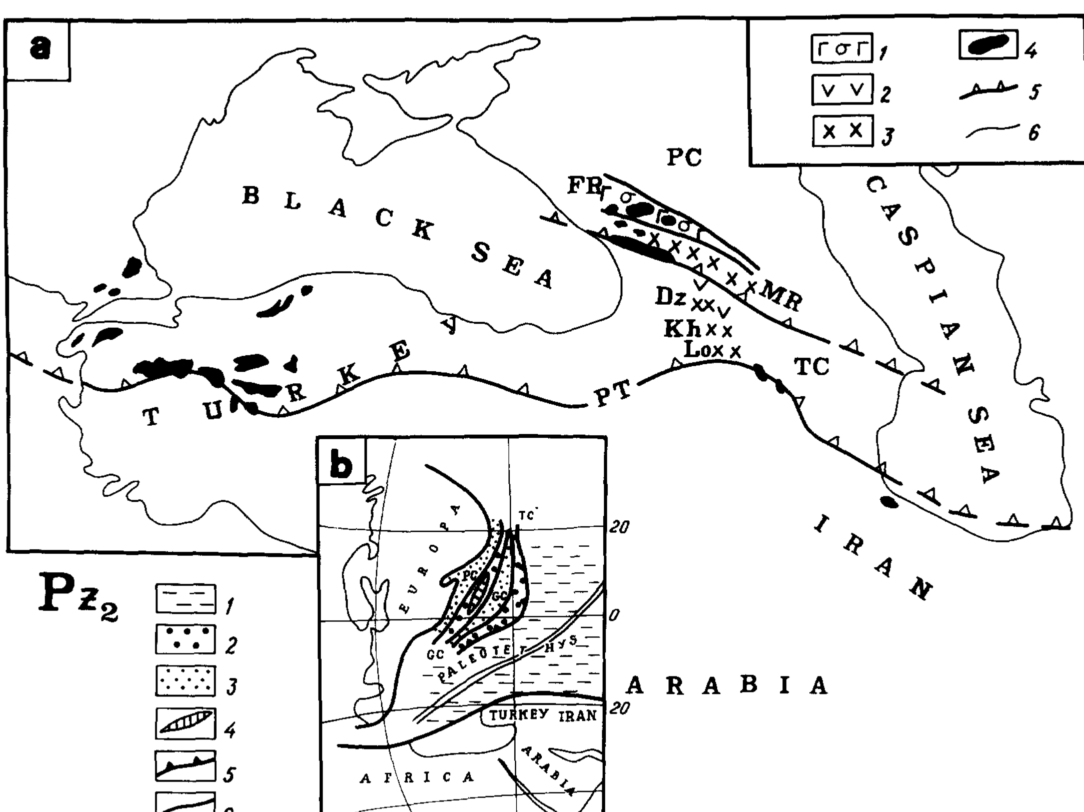

Fig. 1. Tectonic zoning (a) and palinspastic reconstruction (b) of the Caucasus and adjoining regions for the late Middle Palaeozoic. Legend for (a); 1. Devonian bipolar basalt–rhyolitic volcanics, 2. differentiated calc-alkaline volcanic series, 3. plagioclase-granites, diorites and quartz diorites, 4. ophiolities and metaophiolites, 5. ophiolitic suture zones, 6. limits of structural zones; PC, Precaucasus; FR, Fore Range of the Great Caucasus; MR, Main Range of the Great Caucasus; TC, Transcaucasus; Dz, Dzirula massif; Kh, Khrami massif; Lo, Loki massif; PT, suture of Palaeotethys. Legend for (b); 1. Palaeotethys, 2. island arcs (TC, Transcaucasian; GC, Great Caucasian), 3. back-arc basins (GC, Great Caucasian; PC, Precaucasian), 4. Fore Range interarc rift, 5. Subduction zones, 6. Passive plate boundaries.

Palaeozoic the Nakhichevan region belonged to the Gondwana biogeographical province (Leven & Scherbovich 1978). Palaeomagnetic data from the Devonian and Permian red clastics on the northern slope of the Great Caucasus (Northern Caucasian domain) show that this region was situated on the southern margin of Eurasia, this inference being supported by palaeoclimatic, palaeophytological and palaeozoological evidence from the Great Caucasus and Transcaucasus. In the Khrami mass, within the Transcaucasus, the Lower Middle Carboniferous fauna and flora are of Eurasiatic affinities (e.g. Nalivkin *et al.* 1972, Novik & Fisunenko 1977, Jarkov 1978, Leven & Scherbovich 1978). On the basis of this new evidence it is possible to recognise within the Northern Caucasian domain (Fig. 1b) several Palaeozoic structural units that may be compared with these of the present western Pacific. Immediately north of Tethys was the Pontian–Transcaucasian island arc, bordered on the north by the Great Caucasian small oceanic basin. Further north there was the Great Caucasian island arc, separated from the Scythian platform by the Precaucasian marginal sea (Adamia *et al.* 1978).

The Palaeozoic magmatic rocks of the Transcaucasian and Great Caucasian island arcs are mainly granitoids, Upper Palaeozoic shallow-marine to continental acid and calc-alkaline volcanics being of limited occurrence (Figs. 1a and 2a). Granitoids in both of these arcs belong to two major age groups. The older granitoids are Lower-Middle Palaeozoic grey granites represented by biotite–hornblende quartz diorites and granodiorites poor in K-feldspars. In the majority of these rocks silica ranges from 54 to 68%. The younger granitoids are Lower-Middle Carboniferous red granites comprising K-feldspar alaskites and biotite–muskovite and muskovite granites (SiO_2 > 70%). Both island arc granitoid sites reveal a distinct lateral zoning. The positions of the Loki, Khrami and Dzirula granitoid massifs within the Transcaucasian island arc allow a 150-km transverse section to be studied (Fig. 1a). Within the section the K_2O content and the K_2O/Na_2O ratio increases from the south (Loki massif) to the north (Dzirula massif), whereas the CaO content decreases in the same direction. Along the southern margin of the Great Caucasian island arc (Sofia block) K_2O/Na_2O ratios in the granitoids are lower than within the Dzirula massif, but again they increase north towards the Teberda-Digori granitic block. Thus each island arc of the northern margin of Tethys independently reveals a northern polarity, which is more pronounced for the older grey granite (Adamia & Shavishvili 1979). The zoning is similar to the polarity established for granitoids associated with the active margins of the Pacific (Moore *et al.* 1959, Taneda 1965).

It is stressed that the Palaeozoic granitoids of the Transcaucasian island arc may be distinguished from similar rocks in the Great Caucasian arc by a generally lower LIL element content and by their general geochemistry which is characteristic of mantle-derived granitoids.

A lateral zoning within the metamorphics of the Great Caucasian island arc can also be detected. In the central part there are high-T low-P andalusite–sillimanite schists (Chkhotua 1977) derived predominantly from sialic rocks, whereas along the southern margin of the metamorphic belt there are metabasites and metasedimentary rocks belonging to the Laba and Buulgen Series, the Laba

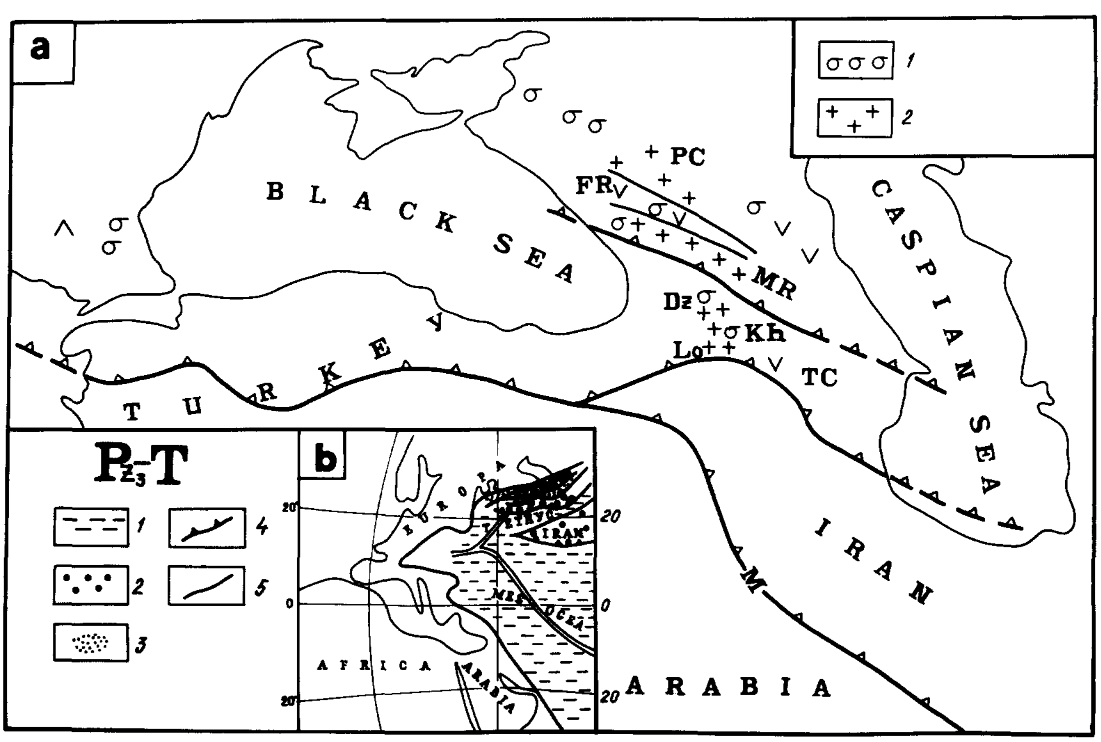

Fig. 2. Tectonic zoning of the Caucasus and adjoining regions for the Late Palaeozoic–Triassic (a) and palinspastic reconstruction for the Late Triassic (b). Legend for (a); 1. Acid volcanics, 2. granites; M, suture of Mesogea; other symbols as in Fig. 1, but note that 4 and 5 in Fig. 2 are 5 and 6 in Fig. 1.

metamorphic rocks being of moderate-P Kyanite–silli manite type. Thus, it appears that the degree and character of metamorphism within the schists depends on their former paleogeographical position. From south to north there is a change from kyanite–sillimanite to andalusite–sillimanite. The moderate-P Kyanite–sillimanite metamorphism in the marginal part of the arc may have been related to a convergent plate boundary along the northern margin of the Great Caucasian small oceanic basin (Chkhotua 1977, Adamia *et al.* 1978).

In the Middle Palaeozoic (Devonian) an inter-arc lift basin (the Fore Range inter-arc rift) developed within the Great Caucasian island arc (Fig. 1b). This inter-arc rifting was marked by comparatively deep-marine sandy–argillaceous turbidite sedimentation and by intense bimodal basalt–rhyolitic volcanic activity, basalts being predominant. The basalts are similar to MORB in their differentiation trends and their low K_2O content, but in their low TiO_2 content they resemble island arc tholeiites (Adamia & Shavishvili 1979).

It seems that the Fore Range inter-arc basin received the ophiolitic nappes that arrived before the Middle Carboniferous. These nappes rest on autochthonous Upper Devonian–Lower Carboniferous rocks within the Fore range inter-arc basin and are transgressed by Namurian and Bashkirian molasse. Some nappes comprise Silurian and Middle Devonian rocks. The ophiolitic association comprises ultramafics, layered gabbros, sheeted dykes, basalt lavas and sedimentary rocks. Ultramafic rocks at the bases of nappes are mainly apolherzolitic serpentinites, some of which are garnet-bearing. Gabbros and gabbro-diorities dominate within the layered complex, but olivine gabbros, troctolites, wehrlites and pyroxenites are also present. The complex has mainly tectonic contacts with the underlying serpentinites and overlying sheeted dykes, but transitions to the latter are also known. Sheeted dykes occur in several nappes and comprise alternations of diabases, gabbro-diabases and microgabbros. Chilled margins and dyke-in-dyke structures are common. Suprisingly, the dykes are orientated subparallel to the general stratification of the nappes. The Volcanic series is characterised by basalts, but in its lower part there are concordant diabase sills. In the upper parts basalts alternate with andesites and dacites. The thickness of the volcanic series exceeds 1000 m. The sedimentary series consists of plagioclase–sericite–quartz sandstones and phyllites alternating with intermediate and acid tuffs. Scarce siltstones and marmorised limestones also occur in the sedimentary series, which has a total thickness of 800 m. All the rocks are metamorphosed to greenschist facies. The greenschist metamorphism makes it difficult to determine the original chemistry of the magmatic rocks. Analyses, based on comparatively immobile TiO_2, P_2O_5, K_2O, FeO, MgO, Cr, V, Co and Ni, indicate the tholeiitic affinities of the layered intrusions. The sheeted dykes and lavas reveal a close similarity to the volcanic rocks of the Scotia back-arc basin. The petrochemical characteristics of the volcanic rocks and the thickness and composition of the sedimentary series of the Fore Range ophiolites differ from those, of oceanic basalts and sediments. Thus it is assumed that they represent the crust of a small oceanic basin.

Geological evidence indicates that the ophiolitic nappes of the Fore Range belt arrived from the south (Baranov & Grecov 1980). Scattered occurrences of ophiolites and meta-ophiolites are known in the south on the Great Caucasian island arc. It seems highly probable that the ophiolites were derived from the Great Caucasian small oceanic basin (Fig. 1b). The metabasites and metasediments of the Laba and Buulgen Series in the frontal part of the arc may be the roots of the nappes (Chkhotua 1977, Adamia *et al.* 1978).

The Hercynian orogeny apparently caused deformation and northward thrusting of the basaltic crust of the Great Caucasian small oceanic basin. But the principal palaeogeographical arrangement of the Caucasian active margin remained unchanged. There was magmatism in the Transcaucasian and Great Caucasian island arcs in the Carboniferous and Early Permian, when acid to calc-alkaline volcanics and granites were formed. The Great Caucasian small oceanic basin between the two arcs remained as a comparatively deep-marine feature in which flyschoid sedimentation continued uninterrupted into the late Palaeozoic–Triassic (Figs. 2a and 2b).

FROM PALAEOZOIC TO MESOZOIC TETHYS: CONTINUITY OR BIRTH OF A NEW OCEAN?

Views on relationships between Palaeozoic and Mesozioc Tethys remain controversial. It is widely accepted that the Hercynian orogeny had reduced Palaeotethys to a shallow epicontinental sea and that the Mesozoic ocean resulted from Late Triassic rifting, obliquely superimposed on the Hercynian structures (e.g. Khain 1975, Knipper 1975, Argyriadis 1975, Ricou 1976, Gamkrelidze 1976, Sokolov 1977). This concept is mainly based on the shallow-marine character of the Upper Palaeozoic sediments, the predominantly pre-Middle Carboniferous age of emplacement of the Palaeozoic ophiolites, and the Late Triassic age of the oldest basalt–radiolaritic series in the Mesozoic ophiolitic complexes of the Tethyan realm. The alkali–basalt composition of the volcanics is thought to be related to the early rifting that initiated Mesotethys (Juteau 1970, 1975).

An alternative explanation is that the Tethys ocean persisted throughout the Palaeozoic and Mesozoic (Stöcklin 1974, 1977, Mossakovski 1975, Adamia 1975, Adamia *et al.* 1977, 1978, 1979, Aubouin 1977). It is thought that the Turkish part of Mesotethys descended from the Palaeozoic ocean, whereas the Iranian part commenced with the initiation of the Zagros rift (Mesogea), which widened during the late Palaeozoic–Early-Middle Triassic causing a general reduction in width of the South Caspian branch of Palaeotethys (Fig. 2b).

The persistence of Tethys throughout the late Palaeozoic–Triassic seems to be indicated by the following observations. Allochthonous sheets of Upper Permian basalt–radiolarites intimately associated with ophiolites are known in the Western Taurus Mountains (De Gracyanski 1972). Basalts in this Permian deep-marine assemblage are alkaline low-TiO_2 tholeiites comparable to the Triassic, Jurassic and Cretaceous volcanics of the East Mediterranean ophiolites (Beccaluva *et al.* 1979). Upper Carboniferous–Lower Permian and Triassic ophiolitic olistostromes are known in Western Anatolia (Brinkmann 1976, Fourquin 1975). Exotic blocks of open-sea Middle Triassic ammonite-bearing limestones occur in the Minor Caucasian ophiolitic belt and are unlike the Triassic deposits of the Southern and Northern Caucasian domains. Carboniferous-Early Triassic abyssal cherts and carbonates crop out on the northern slopes of the Eastern Alborz (Jenny & Stampfly 1978, Chateauneuf & Stampfly 1978). In the Turkish part of the Tethyan realm division into northern (Eurasiatic) and southern (Africa–Arabian) biogeographical provinces was maintained throughout the Late Palaeozoic-Early Mesozoic (Termier & Termier 1974, Enay 1976), the North Anatolian suture representing a persistent divide between the two. In the Caucasian–Iranian parts, the same divisions existed in the Late Palaeozoic–Early Triassic (Leven & Scherbovich 1978, Chateauneuf & Stampfly 1978, Jenny & Stampfly 1978). It is thought to be significant that the northern margin of Tethys remained magmatically active in the Late Palaeozoic–Triassic, when an extensive belt of acid and calc-alkaline volcanics was extruded in the Balkans, Crimea–Caucasus and on the Turan plate (Mossakovski 1975).

Alkaline Upper Triassic ophiolitic basalts and similar Jurassic–Cretaceous volcanic facies are widespread in the ophiolite belts of the Eastern Mediterranean region (Beccaluva *et al.* 1979). Judging from their alternation with radiolarites these volcanics may be remnants of oceanic seamounts rather than the products of initial rifting of continental crust. Thus, the geological evidence indicates the persistence of oceanic crust and its repeated subduction and obduction during the Late Palaeozoic–Triassic. In the western part of the area under consideration the main oceanic axis remains unchanged. The palaeomagnetic data from the Nakhichevan, Central Iran and Alborz show that in the Late Palaeozoic these areas were still close to the Gondwana margin of Tethys, whereas in the Late Triassic–Jurassic they were situated at its Eurasiatic margin. Thus, by the Late Triassic–Jurassic the Minor Caucasian–South Caspian branch of the Tethys seems to have considerably reduced in width, and its oceanic axis to have shifted south into the Zagros basin (Mesogea) (Fig. 2b). Biogeographical data for the Jurassic of Nakhichevan and Iran support this Palaeomagnetic reconstruction (Rostovtsev & Azarian 1971, Enay 1976).

MESOZOIC TETHYS AND ITS CONTINENTAL FRAME

In the Triassic–Early Liassic the Caucasian active margin of the Tethys still comprised the Transcaucasian and Great Caucasian island arcs, seperated by the Great Caucasian small oceanic basin, an area of permanent turbidite sedimentation. It is probable that northwards subduction remained active along the northern periphery of this basin, triggering acid and calc-alkaline volcanism in the Great Caucasian island arc during the Middle-Late Triassic and Early Liassic (Khain 1979, Lordkipanidze 1980).

After the Early Liassic the Great Caucasian island arc was welded to the Scythian platform and then became a shelf zone to the Great Caucasian basin that acquired the position of a marginal sea (Adamia *et al.* 1977) (Fig. 3b). A new stage of spreading affected this basin in the Middle Liassic–Bajocian, when transitional to tholeiitic low-K basalts of MORB geochemical affinities and abundant diabase dyke swarms, were intruded within thick (5000 m) Liassic–Bajocian slates (Lomize & Sukhanov 1974, Adamia *et al.* 1977, Lordkipanidze 1980) (Figs. 3a and b).

No Triassic magmatic or sedimentary rocks are known from the Transcaucasian island arc, which experienced a long period of uplift and denudation before the Liassic. Early Liassic submergence of the Transcaucasian island arc was accompanied by dacite–rhyolitic volcanism of Sinemurian age.

After a period of quiescence, volcanic activity spread throughout the arc in the Bajocian, and then until the Neocomian gradually retreated towards its southern margin. The Jurassic–Neocomian calc-alkaline volcanic belt reveals a distinct northwards polarity, the character of volcanics changing from low-K calc-alkaline in the south to shoshonitic in the north (Fig. 3a). There is also a distinct increase in the K_2O and TiO_2 contents in the products of the final Lower Neocomian volcanic activity (Adamia *et al.* 1977, Lordkipanidze 1980). There is little palaeomagnetic data to indicate that an inter-arc basin evolved within the Transcaucasian arc in the Bajocian, separating its northern Dzirula part from the southern Loki part (Asanidze & Pechersky 1979) (Fig. 3b). Northwards movement of the northern part of the Transcaucasian arc related to inter-arc rifting, may explain the occurrence of late Bajocian–Bathonian folds and gravitational structures in the Great Caucasian sea. As a result, the latter was divided into eastern and western deep-marine troughs linked by a shallow-marine ridge. The thick (1000–1500 m) Upper Jurassic basaltic series in the central part of the Transcaucasian island arc, discovered by drilling (Poti and Samtredia environments) may represent some of the products of this hypothetical inter-arc basin, but geological and palaeomagnetic evidence is as yet too meagre to allow a definite conclusion.

In the Minor Caucasian branch of Tethys, MORB-type tholeiites as well as alkaline, basalts probably related to sea-mounts or leaky transform faults, were formed in the Middle Jurassic–Neocomian (Zakariadse & Knipper in press).

The Iranian block experienced intense rifting and block-faulting at about the time of the Triassic–Jurassic boundary, and the faulting was locally accompanied by continental or shallow-marine alkali-basalt volcanism (Stöcklin 1974). The 200-m thick, high-TiO_2, alkaline-basaltic series of Nakhichevan, unconformably resting on

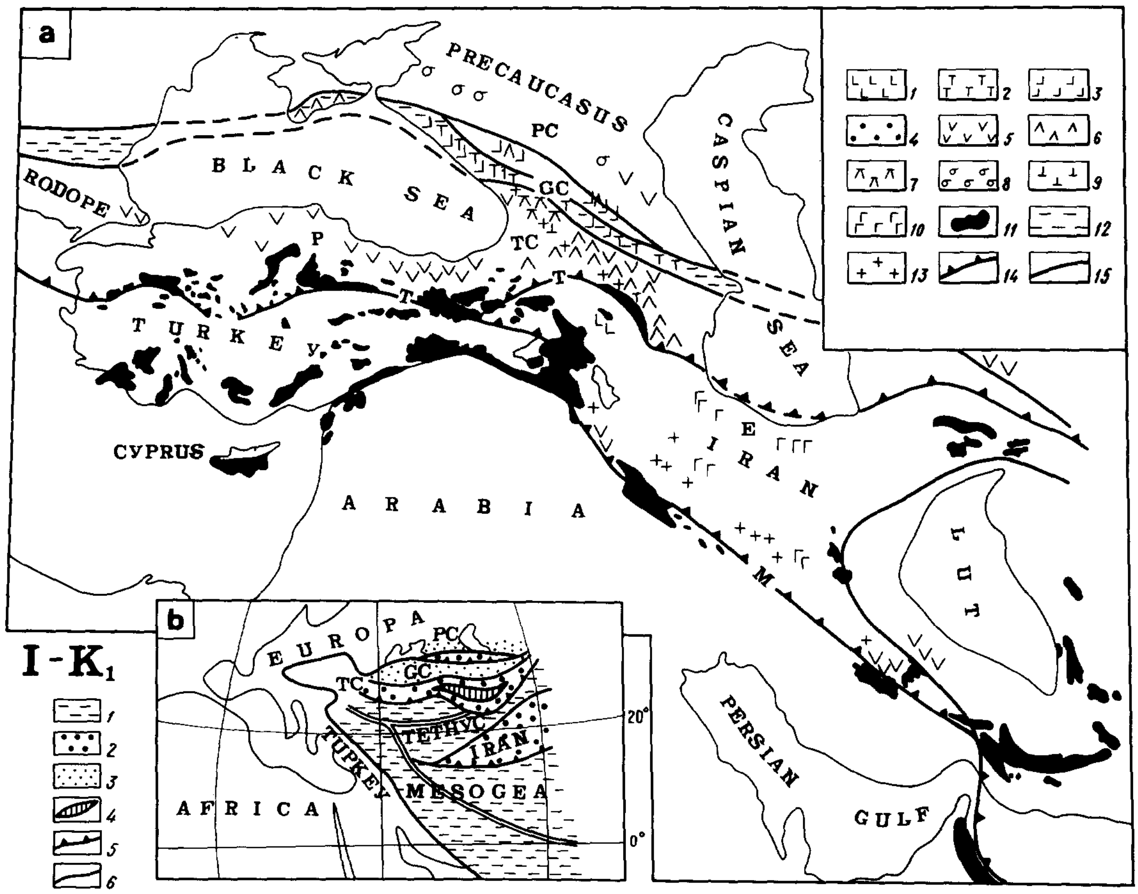

Fig. 3. Tectonic zoning of the Caucasus and adjoining regions for the Jurassic–Neocomian (a) and palinspastic reconstruction for the Middle Jurassic (b). Legend for (a); 1. Low-TiO_2, Low-K_2O basaltic volcanics, 2. MORB-type tholeiitic basalts, 3. Low-TiO_2 alkaline basalts, 4. high-TiO_2 alkaline basalts, 5. differentiated series, 6. low and normal K_2O calc-alkaline series, 7. high-K_2O calc-alkaline and shoshonitic series, 8. phyolites and dacites, 9. trachytes, 10. basaltic series, 11. ophiolites, 12, flysch, 13. granitoids, 14. suture zones, 15. limits of main tectonic units; P, Pontides; E. Alborz; T, suture of Tethys; M, Mesogean suture; other symbols as in Fig. 1.

Middle Triassic deposits and overlain by Lower Bajocian rocks, may be related to the same processes. Starting from the Late Jurassic the Iranian block, affected by intense calc-alkaline volcanic activity (volcanic rocks and intrusives of the Sanandaj–Sirdjan zone) may be regarded as an island arc on the northern margin of the Mesozoic ocean (e.g. Forster *et al.* 1972 Stöcklin 1974, 1977).

During the Albian–Late Cretaceous, two types of volcanic series were formed in the Minor Caucasian branch of Tethys. The association of high-TiO_2 tholeiites with alkali basalt-trachytes, strongly resembling a volcanic association of seamounts and oceanic islands, is widespread, along with the low-TiO_2, low-K_2O tholeiitic basalts and basaltic andesites of oceanic island arc affinities. These volcanics alternate with radiolarites, micritic limestones and ophiolitoclastic turbidites (Zakariadze *et al.* in press). Thus the Minor Caucasian oceanic basin is regarded as a complex oceanic feature with an oceanic island arc, seamounts and oceanic islands. The date of ophiolite emplacement on the sialic northern and southern island arcs (terminal Albian–Early Cognacian) is close to the time of eruption of the volcanic series. Thrusting of the ophiolites is considered to have been a result of the collision of the sialic Transcaucasian and Iranian arcs with the internal seamounts and oceanic island arc of the Minor Caucasian basin.

The second of the Mesozoic volcanic cycles of the Transcaucasian arc (Aptian–Maestrichtian) mainly coincided with this collision. The volcanic belts of this cycle show features which are distinctive of an unusual geodynamic environment. The character of volcanism is different in the western and eastern parts of the Transcaucasian arc. In the western part a differentiated calc-alkaline volcanic series was formed, while along its eastern periphery volcanic activity was restricted to a narrow transverse zone following the Caspian border. A thick (1500 m) series of low-TiO_2, high-Al_2O_3, high-K_2O basalts occurs in the transverse zone (Fig. 4a). In contrast to the older and younger 'andesite' belts the calc-alkaline volcanic belt of the western Transcaucasus lacks any distinct polarity and is characterised by rapid and chaotic compositional changes. In the western Pontic continuation of the belt a northwards polarity is well expressed (Lordkipanidze 1980) (Fig. 4a). It is to be stressed that in the Pontian part of the arc, ophiolite obduction (Campanian–Maestrichtian) postdated the main stages of volcanic activity. As in the previous cycle, volcanic activity gradually retreated to the southern margin of the arc and its final products are characterised by higher TiO_2 and K_2O contents. The petrochemical peculiarities of the calc-alkaline volcanic belt in the western Transcaucasus probably indicate some disturbance in the subduction

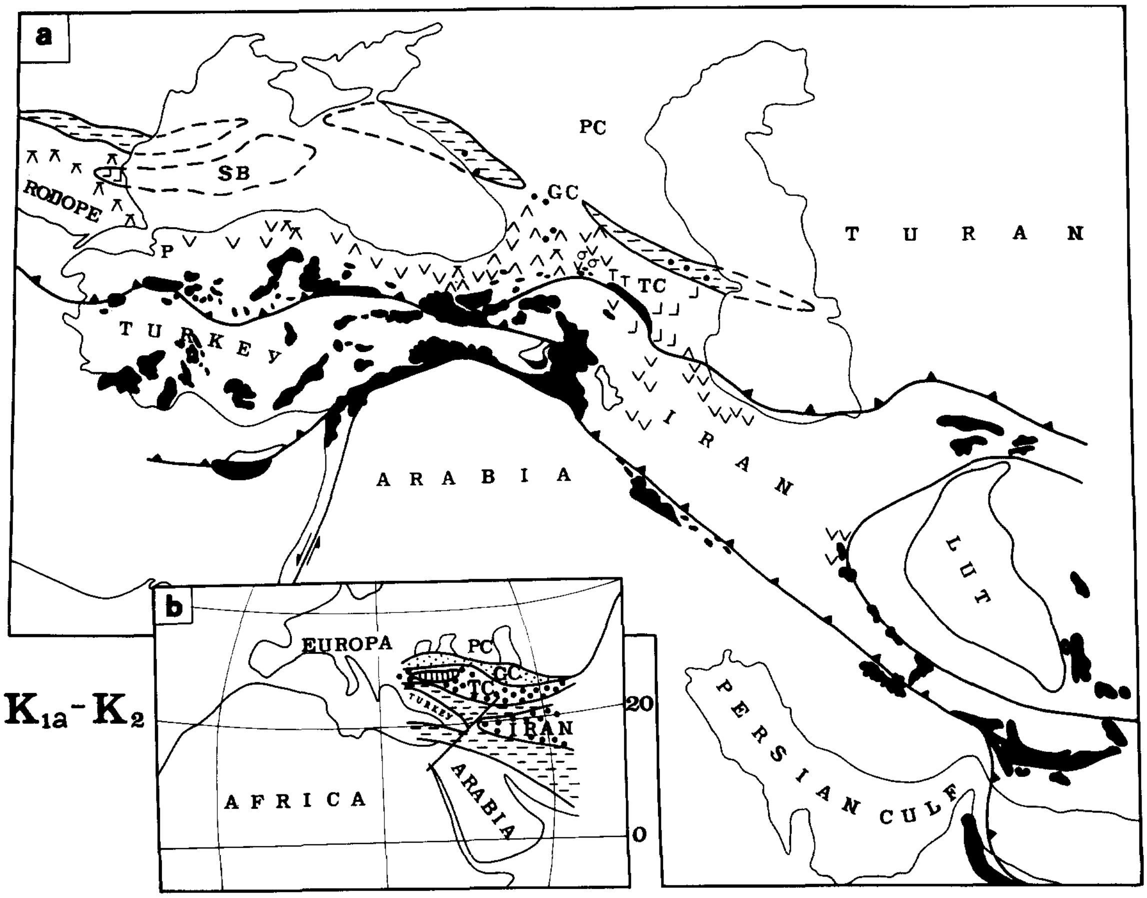

Fig. 4. Tectonic zoning of the Caucasus and adjoining regions for the Albian–Late Cretaceous (a) and palinspastic reconstruction for the late Cretaceous (b). In (a) SB indicates the Burgas-Western Black Sea interarc rift (Boccaletti *et al.* 1974). Other symbols as in Figs. 1 and 3.

mechanism. Although the petrochemical characteristics (low-TiO_2, high-Al_2O_3) of the volcanic series of the eastern Transcaucasus suggest subduction-generated volcanic activity, the predominance of basalts implies a tensional environment. The eastern Transcaucasus, where ophiolitic nappes were thrusted farthest north, towards the central part of the arc, seems to represent an area of maximum compression during ophiolite emplacement. It is possible that a tensional transverse fault zone was formed here, blocks moving away from the compressional axes so that the subduction-generated magmas could reach the surface only along the transverse fault zone. It is also possible that a relationship exists between such transverse tension and the formation of the Caspian basin, the enigmatic deep-marine feature of the Caucasus.

Volcanic activity in the Great Caucasian marginal sea was restricted to the western and eastern flysch troughs, 300-m thick high-TiO_2 alkaline basaltic sequence of Albian–Senomanian age occurs locally, accompanied by diabases and small gabbro intrusives of the same composition.

South of the Minor Caucasian basin significant calc-alkaline volcanic activity affected the northern part of the Iranian island arc (Fig. 4a) in the Aptian–Maestrichtian. In the western Alborz it produced a 1000–1500 m thick series (Stöcklin 1974). An Albian–Senomanian andesite–dacitic series (250 m) is known in the Nakhichevan part of the arc. This series is thought to be related to northwards subduction in the Zagros basin (Forster *et al.* 1972, Stöcklin 1974, Lordkipanidze 1980).

It is assumed that in the Late Cretaceous, a period of intense block-faulting in the Anatolian–Tauride part of the Africa–Arabian carbonate shelf (Ricou *et al.* 1975), the youngest southwestern branch of Tethys developed. It is now marked by Maestrichtian–Palaeocene basalts and pelagic carbonate sediments in Iranian Kurdistan and Southern Anatolia (Braud & Ricou 1975). Subduction along the northern margin of this basin triggered Palaeogene calc-alkaline volcanic activity south of the North Anatolian suture, that is on the former Anatolian carbonate shelf (Fig. 5a & b). It seems that remanents of the oceanic crust of the Anatolian–Minor Caucasian basin were consumed during the Palaeogene, the process leading to the development of an extensive andesitic belt within the Pontian–Transcaucasian arc, that reveals an independent northern polarity. The extensive Palaeogene volcanic belts of the Pontian–Transcaucasian and Nakhichevan–Iranian island arcs are characterised by a high proportion of high-K_2O calc-alkaline and shoshonitic rocks. As in the previous cycles there was a marked increase in K_2O and TiO_2 contents during the final stages of volcanic activity (Lordkipanidze *et al.* 1977). On the rear side of these belts, the Black Sea–Adjarian and Talysh–South Caspian back-arc basins developed, with areas of basaltic volcanism and deep-marine turbidite sedimentation (Figs. 5a & b) (Adamia *et al.* 1974, 1977).

Palinspastic reconstructions for the Palaeogene, diminishing distinctions between the southern and northern Tethyan biogeographical provinces, and the character of the volcanic activity on the island arcs indicate reduction of oceanic spaces and a passage from a 'Pacific' to a 'Mediterranean' stage of development (Fig. 5b) (Adamia *et al.* 1977).

It is assumed that limited areas of oceanic crust persisted into the Neogene in the southern branches of the Tethys (Mesogea). Consumption of this crust down northward-inclined subduction zones caused the development of the extensive 'andesitic' neovolcanic belt of the Alpine–Himalayan orogen. In Turkey, Caucasus and Iran this belt reveals a distinct northern polarity (Fig. 6) (Lordkipanidze 1980).

CONCLUSIONS

Palaeomagnetic, biogeographical and geochemical evidence indicates that the Minor Caucasian ophiolitic suture marks the main axis of Palaeozoic Tethys. That part of the Caucasus situated north of the suture (i.e. the Northern Caucasian domain) represents a 'West Pacific type' active margin that comprised the Transcaucasian primitive island arc, the Great Caucasian small oceanic basin, the Great Caucasian mature island arc and the Precaucasian marginal sea, each characterised by its own magmatic, metamorphic and sedimentary facies. South of the suture, Nakhichevan (the Southern Caucasian domain) was part of the Gondwana carbonate shelf.

Towards the Late Triassic the Minor Caucasian oceanic basin that descended from Palaeozoic Tethys, was reduced to a narrow northern branch of the Mesozoic ocean, and separated the two en échelon Pontian–Transcaucasian and Nakichevan–Iranian island arcs of its northern margin. The Mesozoic volcanics and sediments of the Minor Caucasian basin, preserved within the ophiolitic complexes, bear a strong resemblance to the ophiolitic volcanic and sedimentary facies elsewhere in the Eastern Mediterranean. The character of these facies indicates that this part of the Tethys represented a complex oceanic structure with oceanic island arcs, chains of seamounts and oceanic islands. In the late Palaeozoic–Mesozoic the main oceanic axis gradually shifted south into the young southern branches of Tethys that separated large blocks from the Africa–Arabian carbonate shelf. These blocks later evolved as a system of volcanic and remanent island arcs and back-arc basins within the northern active margin of Tethys. The system was affected

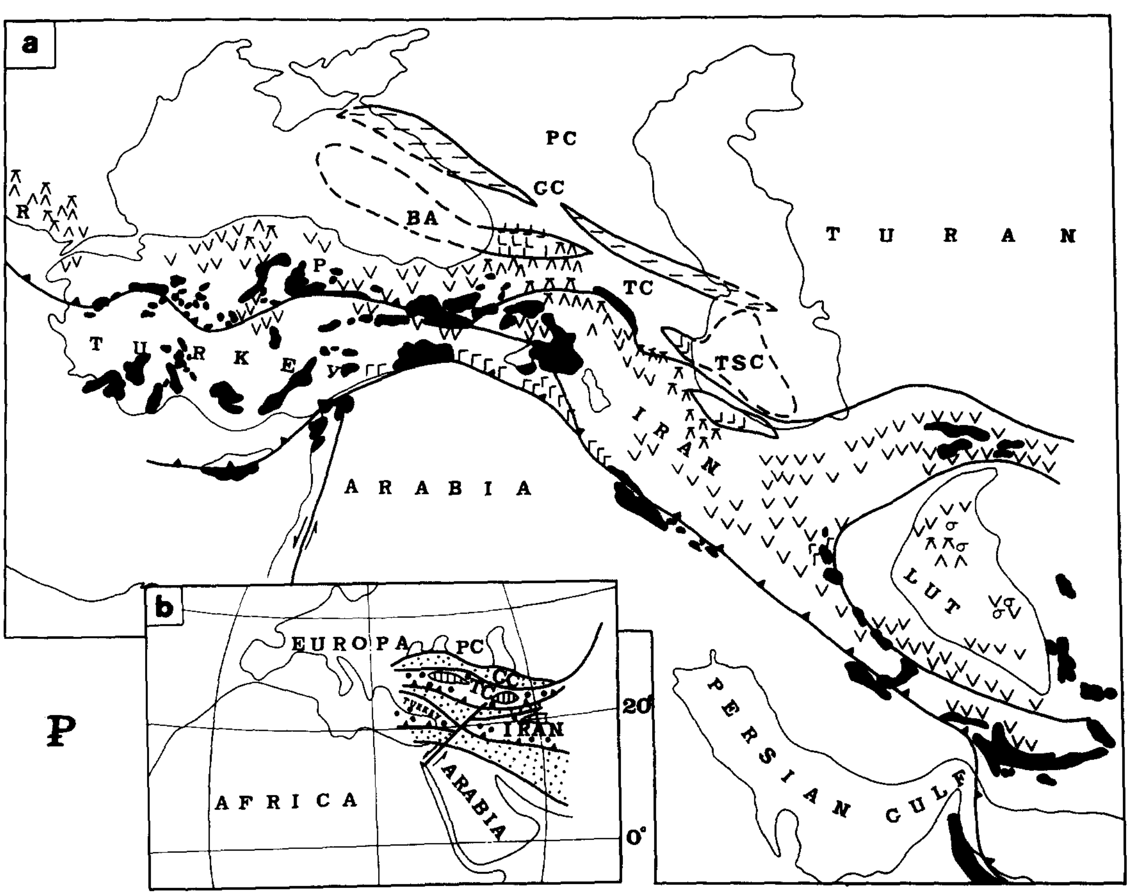

Fig. 5. Tectonic zoning (a) and palinspastic reconstruction (b) of the Caucasus and adjoining regions for the Palaeocene–Eocene. Legend for (a); R, Rhodope massif; BA, Black Sea–Adjarian; inter-arc rift TSC, Talysh-South Caspian inter-arc rift; other symbols in Figs. 1 and 3.

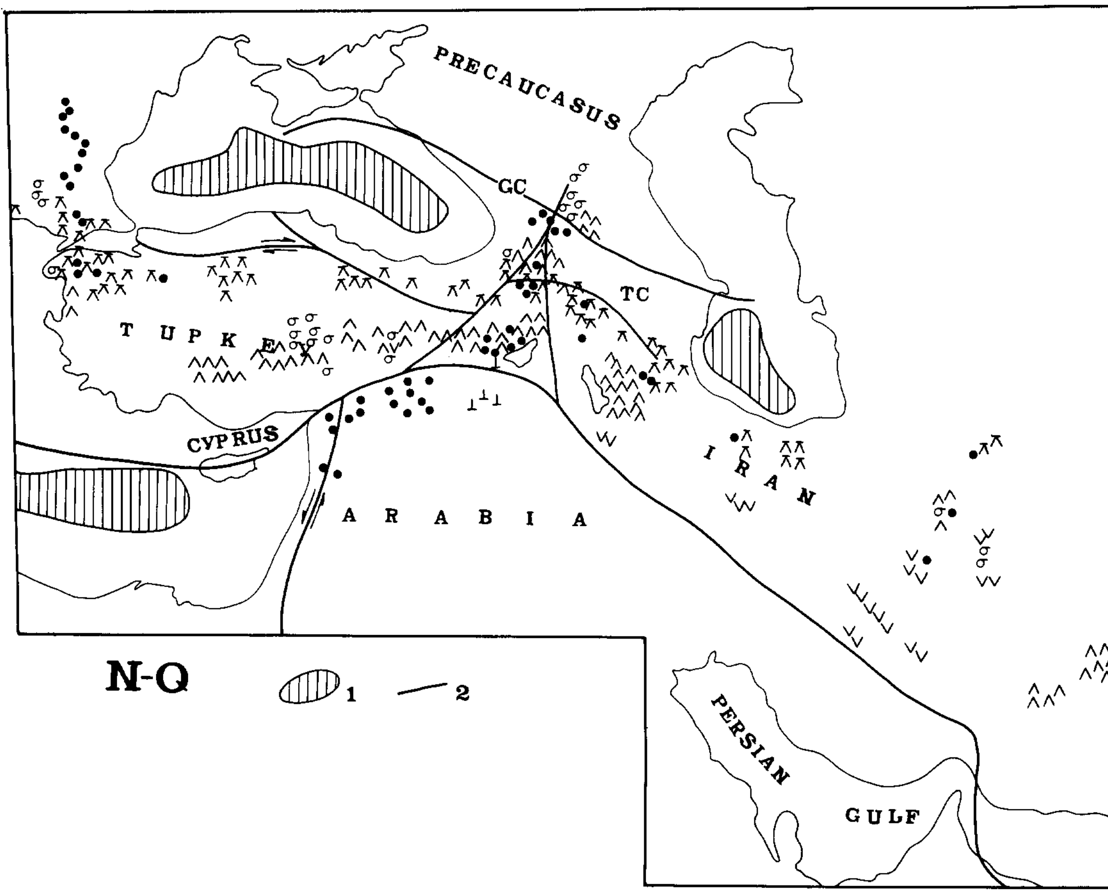

Fig. 6. Neotectonic structural elements and Neogene–Quaternary volcanism of the Caucasus and adjoining regions. Legend; 1. suboceanic crust, 2. main faults, other symbols as in Figs. 1 and 3.

by repeated structural rearrangements and gradually migrated south with the displacement of the oceanic axis. In the Palaeogene, the northern Palaeozoic branches of Tethys seem to have been closed, whereas the 'young' southern part (i.e. Mesogea) was reduced to a Mediterranean type intracontinental sea with limited areas of oceanic crust apparently persisting into the Neogene.

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