Paleogeography of the Ukrainian Carpathians, the Crimea, and the Caucasus

by

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INTRODUCTION

Two main tectonic units can be distinguished in the Crimean-Caucasian region: the young Scythian platform in the north, and the Alpine folded area in the south (Fig. 1). In the Ukrainian part of the East Carpathians, the Alpine folded region directly adjoins the southwestern margin of the Russian platform along a system of low-angle thrusts. In the Crimea and the North Caucasus, the southern margin of the Scythian platform was involved in Alpine deformation and has been reworked at differing intensities, which makes it difficult to identify a precise boundary between these tectonic units.

The northernmost tectonostratigraphic units of the Alpine folded belt in the Carpathian-Caucasian region are superimposed on the marginal parts of the East European and Scythian platforms. These units are the pre-Carpathian, Indol-Kuban, East Kuban, and Terek-Caspian piedmont foredeeps, which were infilled with Neogene molasse. South of the piedmont lie the external folded zones of the Alpine belt, the meganticlinorium of the East Carpathians (External Flysch Carpathians), Southern (Mountainous) Crimea, and the Greater Caucasus. Continuing to the south are the quasi-platformal but rather complicated tectonostratigraphic units of the Inner Carpathians and the Transcaucasus — considered by many investigators to be "median massifs" (Pannonian, Pontine-Transcaucasian, South Caspian) with granitic-metamorphic basements formed during the late Baikalian, Caledonian, and Hercynian orogenies.

The ophiolitic suture zone of the Lesser Caucasus (Sevan, Sevan-Akeran, Sevan-Zangezur) extends westward through North Anatolia and the Vardar ophiolitic suture zone into the Transcarpathians. These ophiolitic sutures delimit the southern margin of the median massifs of the Inner Carpathians, Pontides, and Transcaucasus. They separate two different geological provinces of the Carpathian-Caucasian region: Hercynian folding, granitoid magmatism, metamorphism, and endogenic ore formation are intense in the northern provice, whereas they are actually lacking in the southern provice — the Paleozoic section is represented by monotonous shelf carbonates. The regions south of these ophiolitic sutures are considered to be fragments of the northern Gondwana carbonate shelf.

The structure of the ophiolitic suture zone is very complicated — in its present form it represents a narrow, intensely folded synform with extensive tectonic melanges and overthrusts.

The quasi-platform tectonic zones of the Carpathian-Caucasian region were repeatedly fragmented during Alpine tectonogenesis. As a result, troughs formed within them that were filled with Cretaceous-Paleogene volcanics and turbidites (Adjara-Trialetian and Talysh in the Transcaucasus). Alpine intermontane molassic depressions (Transcarpathian, Rioni, Kura, Araks) and Neogene-Quaternary volcanic highlands (the Vigorlat-Guta ridge in the Transcarpathians, Armenian, and the Djavakheti highlands and plateau in the Transcaucasus) are superimposed over the quasi-platform structures, as well as over the margins of Mountainous Crimea and the Greater Caucasus.

The Black Sea, Azov, and Caspian Basins cover various structures of the Carpathian-Caucasian region. In its western part, the Black Sea Basin covers the East European, Moesian, and Scythian platforms. In the north, the Black Sea shelf includes submerged parts of Mountainous Crimea and the Greater Caucasus, and its eastern margin covers the Rioni (Kolkhis) depression and Adjara-Trialetian folded zone. The Central and Southern Caspian Basins overlap various structures of the Caucasus, the young Scythian platform, the Greater Caucasus, the Kura depression, and the Talysh foldbelt (in part).

The deep marine parts of the Black Sea and Southern Caspian Sea, underlain by basaltic crust, lie within the limits of the northern (Eurasiatic) province of Carpathian-Caucasian regions, to the rear of the Vardar-North Anatolian-Lesser Caucasian-Karadag ophiolitic suture zone.

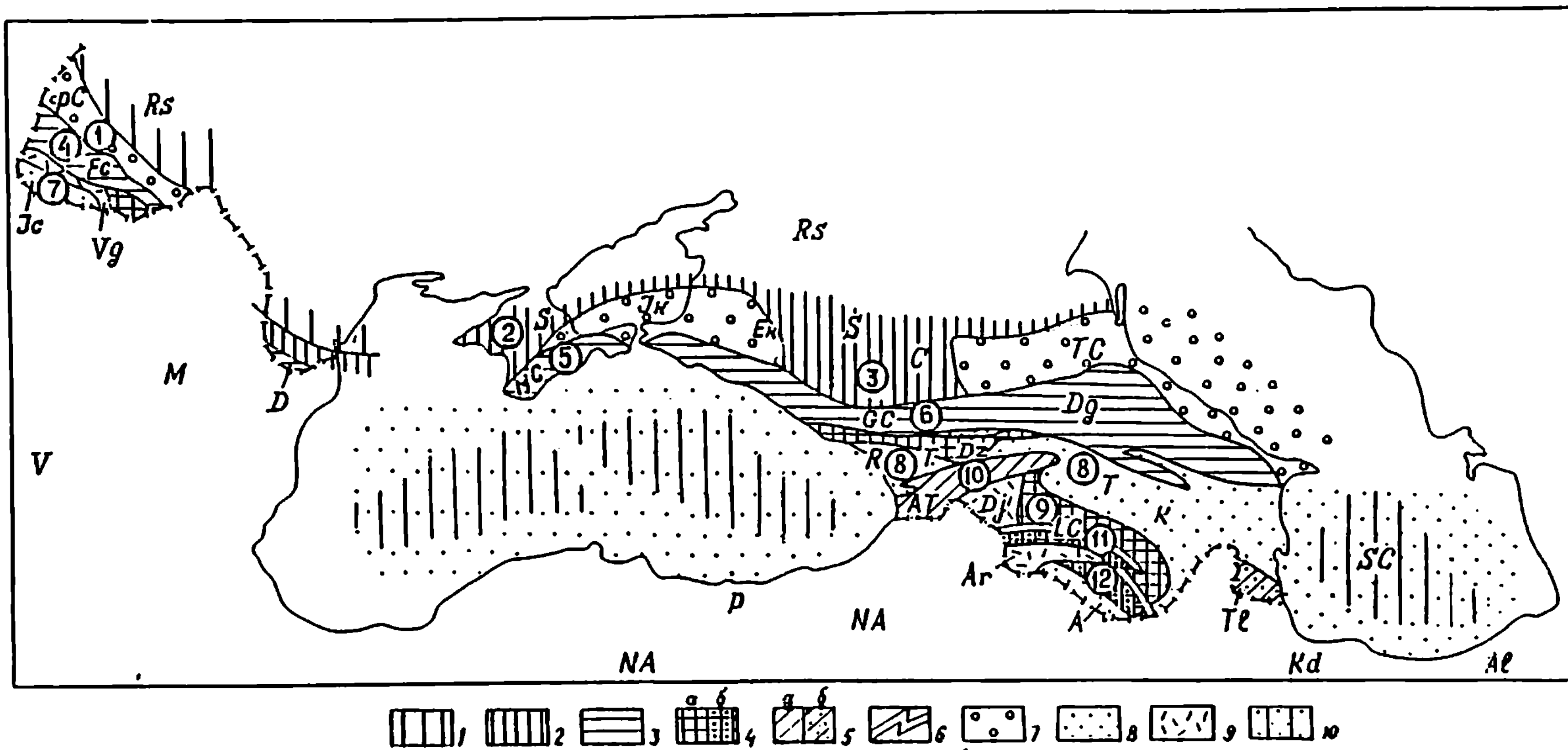

Fig. 1. The tectonic zonation of the Carpathian-Caucasian region. Legend: 1, Russian platform; 2, young Scythian platform; 3, external belt of the Alpine folded area — meganticlinorium of the East External Carpathians, Mountainous Crimea, and the Greater Caucasus, North Dobrogea; quasi-platform regions; 4a, salients of pre-molassic basement of the Pannonian and Transcaucasian Median Massifs; 4b, salients of the pre-molassic basement of the Lesser Caucasian part of the Iranian quasi-platform area; 5, paleorifts of the Transcaucasian Median Massif: 5a, Adjara-Trialeti; 5b, Talysh; 6, Lesser Caucasian ophiolitic suture; 7, foredeeps; 8, intermontane troughs; 9, volcanic highlands; 10, "granite-free" parts of the Black Sea and South Caspian Basins.

The circled numbers 1–12 refer to stratigraphic columns shown in Volume II of this series: Rakús *et al.* (1989, pp. 202-214).

Key: A, Aras depression; Al, Alborz; Ar, Armenian highland; AT, Adjara-Trialeti; D, Dobrogea; Ds, Dagestan; Dj, Djavakheti highland; Dz, Dzirula; EK, East Kuban foredeep; FC, Flysch Carpathians; GC, Greater Caucasus; IC, Inner Carpathians (Transcarpathians, Pannonian); IK, Indol-Kuban foredeep; K, Kura depression; Kd, Karadag ophiolitic suture; LC, Lesser Caucasian (Sevan, Sevan-Zangezure) ophiolitic suture; M, Moesia; MC, Mountainous (Southern) Crimea; NA, North Anatolian ophiolitic suture; P, Pontides; pC, pre-Carpathians foredeep; R, Rioni (Kolckis) depression; Rs, Russian (East European) platform; S, Scythian (Ciscaucasian) platform; SC, South Caspian; T, Transcaucasus; TC, Terek-Caspian foredeep; Tl, Talysh; V, Vardar; Vg, Vigorlat-Guta highland.

PALEOGEOGRAPHY

The basic stratigraphic data from which the twelve paleogeographic maps were developed are summarized in twelve stratigraphic columns (see Volume II of this series: Rakús *et al.*, 1989, pp. 202-214). The detail available varies considerably and, in consequence, the paleogeographic reconstructions of the East Carpathians, Mountainous (southern) Crimea, and the Greater Caucasus fold zone are better documented in terms of both information and field exposure.

Reconstructions of the Scythian platform and the Caucasian intermontane depressions are based on scanty drilling data, and reconstructions of the marine areas occupied by the waters of the Black, Azov, and Caspian Seas are based on geophysical and indirect geological data. In the westernmost part of the region, the Pannonian depression, Moesia, Balkans, and Pontides are given as in Dercourt *et al.*, (1986), for correlation only.

Global reconstructions of continents were used as the basis for the suggested paleogeographic reconstructions of the Carpathian-Caucasian region.

Regional geological and paleomagnetic data for the Carpathians, Caucasus, and Crimea indicate a position of separate block-microplates within the framework provided by the relative positions of stable Africa, Arabia, and Eurasia.

Paleomagnetic data are in agreement with geological and paleobiogeographical evidence, pointing to the existence of several belts in the Caucasus and the adjoining regions that have distinctive geological histories. These are the Scythian platform, the Greater Caucasus, the Transcaucasus-Pontides, and the Lesser Caucasus-Alborz-West Iran regions. With respect to their position relative to African-Arabian and Eurasiatic continents, these belts can be grouped as Northern Tethys (Eurasian) and Southern Tethys (Gondwanan). The Scythian platform, Greater Caucasus, and Transcaucasus-Pontian belts are attributed to the Northern Tethys. Anatolia-Taurus and the Lesser Caucasus are assigned to the Southern Tethys.

Brief descriptions of each of the paleogeographic maps follow.

Anisian (Map 1, Fig. 2)

The Early-Middle Triassic period is the most obscure in the Crimea-Caucasian region because rocks of this age are absent from many of the tectonic units. The Hercynian orogeny, which was very intense in the Caucasus, was followed by a major reorganization of Tethyan margins, when not only the Gondwanian margin, but also the Northern Tethys upper Paleozoic volcanic arc may have been fragmented and the fragments displaced from their original position.

Shelf carbonates were deposited on the Scythian margin during the Anisian, and only in the upper Middle Triassic does the presence of sandy-argillaceous sediments with local andesitic volcanism indicate birth of a volcanic arc-island arc system along the northern margin of Tethys.

A deep marine basin extended south of this volcanic arc. The northern continental slope-continental basement deposits seem to be represented by the Tauric series of Mountainous Crimea. The Küre ophiolites of the Northern Pontides, associated with Permian-Triassic turbidites, may have originated in the same basin (Sengör *et al.*, 1985). This sea probably extended westward into North Dobrogea (Romania) and the Kotel zone of Bulgaria, but its connection with the Carpathians is dubious.

The topmost part of the Dizi series on the southern slope of the Greater Caucasus seems to be the eastern homologue of the Tauric series. The Dizi series represents a Devonian to terminal Triassic sequence of the deep-marine argillites, cherts, and sand-argillaceous turbidites with olistostromal horizons. The rocks, metamorphosed to phyllites and black slates, are dated by conodonts, corals, and foraminifers. The paleogeographic position of the Dizi series is highly controversial. Belov (1981) considered the Dizi series to be Southern Tethys continental slope-basin deposits, accreted to the Scythian platform in the terminal Triassic. Kazmin (this volume) considers the Devonian to Middle Carboniferous part of the Dizi series as a terrain formed at the Gondwana passive margin of the Paleotethys and accreted to the European margin during the Hercynian orogeny. The Upper Carboniferous to Triassic part of the Dizi is interpreted by Kazmin as European fore-arc deposits superimposed on the Hercynian terrain. Contrary to the above authors, we think that the evidence presently available is more consistent with the European origin of the entire Dizi series. Major arguments in favor of the latter concept are include the following. The Devonian and Carboniferous levels of the Dizi consist of extensive horizons of volcaniclastic turbidites (volcanic matter ranging in composition from basalt to rhyolite). Olistostromes of the same age comprise huge blocks of arc-type basalts and basaltic andesites. Thus, a relationship with the European active margin seems more probable. There is no indication of a structural or stratigraphic break between the Devonian and Middle Carboniferous (Moscovian stage included), and the series is homogeneous and seems to be perfectly continuous. The Devonian to Carboniferous conodonts of the Dizi series are similar to the coeval conodonts of the

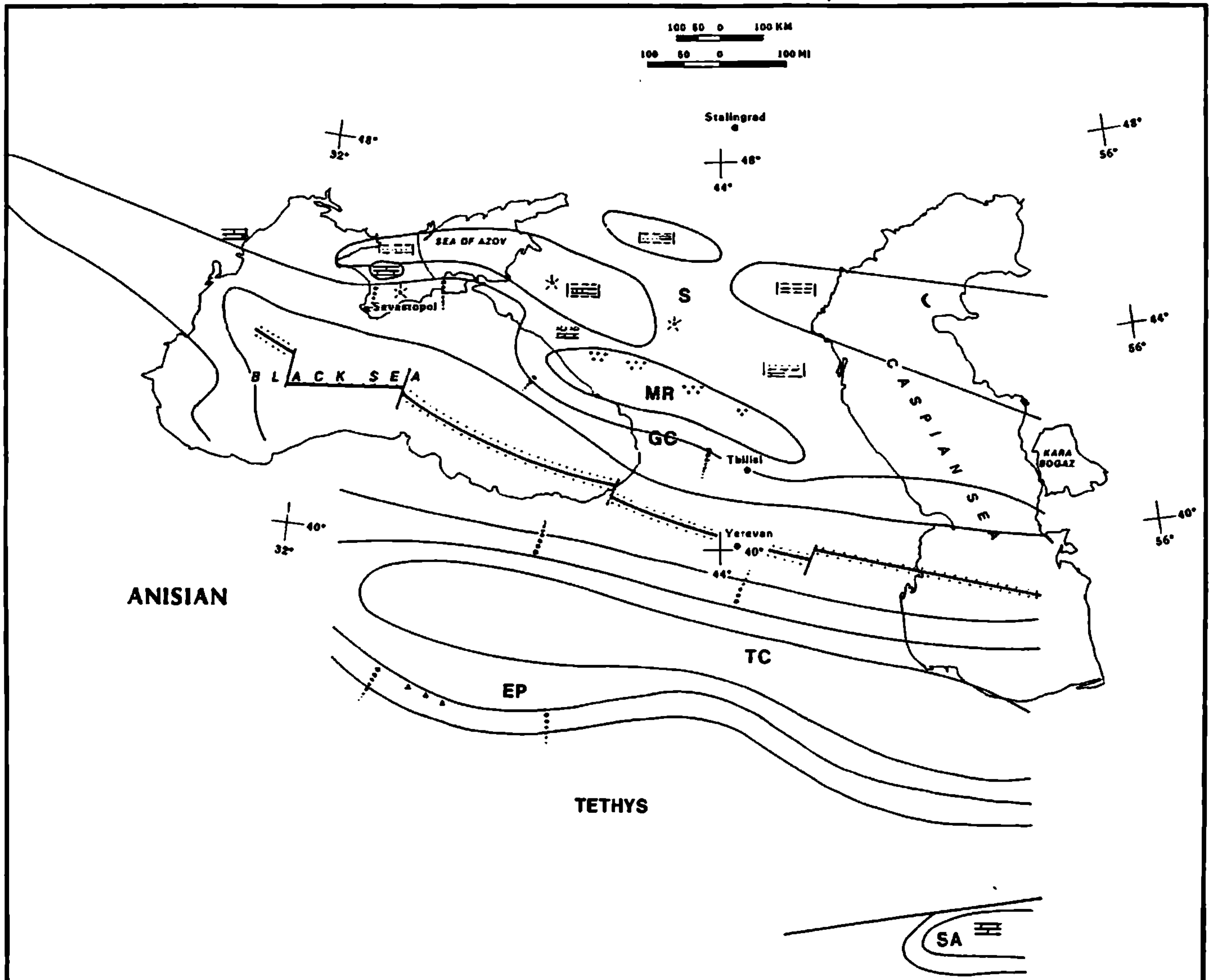

Fig. 2. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the Anisian; see Map 1.

Northern Caucasus, the pre-Caucasus, and the Donets Basin at the European margin, but they have nothing in common with the conodont fauna of southern Armenia, part of the Gondwana Paleozoic shelf. It is true that the difference may be attributed to the different depths of the corresponding basins and that conodont provincialism remains poorly studied, but the close affinities of the Dizi and the Scythian conodonts are indicative of closely interrelated basins. In the Lower and Middle Triassic, the faunal assemblages of the pre-Caucasus, the Northern Caucasus, and the Greater Caucasus are also characteristics of the Northern Tethys province.

A Northern Tethys position for these paleogeographic units is supported by paleomagnetic data for the late Paleozoic and early Mesozoic rocks of the northern slope of the Greater Caucasus (Asanidze *et al.*, 1979, 1980).

In the Western and Central Pontides, the latest Triassic-early Liassic Karakaya olistostromes and mélange of ophiolitic and sialic blocks are metamorphosed to a blueschist facies; this may be a result of a blocked subduction. Triassic rocks are unknown in the Eastern Pontides and Transcaucasian sialic blocks and, hence, the Triassic history of that region is obscure. They may be considered as parts of the Triassic volcanic arc or as passive sialic blocks. There are no data to discriminate whether the Eastern Pontides and Transcaucasus represented parts of a single sialic block, as shown on the paleogeographic map for the Anisian (Fig. 2, Map 1), or whether they represented separate scattered blocks belonging to the Northern Tethys realm. The Triassic ophiolites known in the Soviet Transcarpathians and Inner Carpathians belong to the Carpathian-Dinaride-Vardar branch of Tethys.

The Lower-Middle Triassic deposits of the South Armenian block are shelf carbonates, whereas the Upper Triassic is represented by coal-bearing sandstones and argillites of Shemshak-type, very similar to the Upper Triassic deposits of Central Iran.

Norian (Map 2, Fig. 3)

An andesitic belt formed on the Scythian Platform during the Norian-Rhaetian period, with volcanic activity persisting locally into the Liassic (lower Pliensbachian). This belt, which has a distinct northern polarity, seems to be related to northward subduction beneath the Scythian platform. Norian Tauric turbidites in Mountainous Crimea consist of tholeiitic basalts and basaltic andesites (lava flows with insignificant amounts of volcaniclastics). Their bulk chemistry indicates that the rocks are transitional from MOR to arc tholeiitic and may represent products of back-arc rifting behind the Western Pontides arc, as suggested by Kazmin (this volume).

Two facies zones can be distinguished in the uppermost Triassic of the Mountainous Crimea flysch trough — a northern zone with terrigenous sediments and a southern zone with carbonate deposits — implying a northern source for the terrigenous deposits. In the Dizi Basin, terrigenous argillites and turbidites with an admixture of volcanoclastic and pyroclastic matter continued to accumulate during the Late Triassic. Both basins are characterized by medium to high hydrodynamic activity, with turbidity currents and submarine slumping.

The "Iranian-type" Upper Triassic coal-bearing deposits of the South Armenian block belong to the Northern Tethys realm, according to their facies, flora, and paleomagnetic evidence.

Thus, the major paleogeographic units in the Crimea-Caucasus area are the Scythian volcanic arc, with the Dizi fore-arc basin continuing westward by the back-arc basin of Mountainous Crimea lying behind the Western Pontian arc. Passive blocks of the Eastern Pontides, Northern and Southern Transcaucasus, and southern Armenia are scattered in the Northern Tethys realm.

At the end of the Triassic, a major tectonic event affected the Pontides as well as the different units of the Caucasus and Crimea. Folding occurred in the flysch basins of the Precaucasus. The Crimean plain, Karakaya olistostrome, developed and a subduction mélange formed along the southern margin of the Western and Central Pontides.

The Dizi series that was deposited in the Greater Caucasian sea was folded, with incipient metamorphism, and became partly emergent. It is probable that a residual narrow basin survived and continued to evolve during the Liassic. This is suggested by the close similarity of Triassic and Liassic sediments and the fact that there seems to be a transitional passage between the Triassic and lower Liassic (Sinemurian) deposits in several sections marked by black slates. Recently, these slates have been shown to contain Rhaetian-Hettangian marine palynomorphs, confirming their transitional position. Sinemurian shallow marine conglomerates, sandstones, and acid volcanics were replaced by deep marine black slates in the axial part of the basin.

However, it must be noted that the relationship between the Dizi series and the Liassic black slates is controversial and several researchers believe that there is no continuity between the two (see Kazmin, this volume).

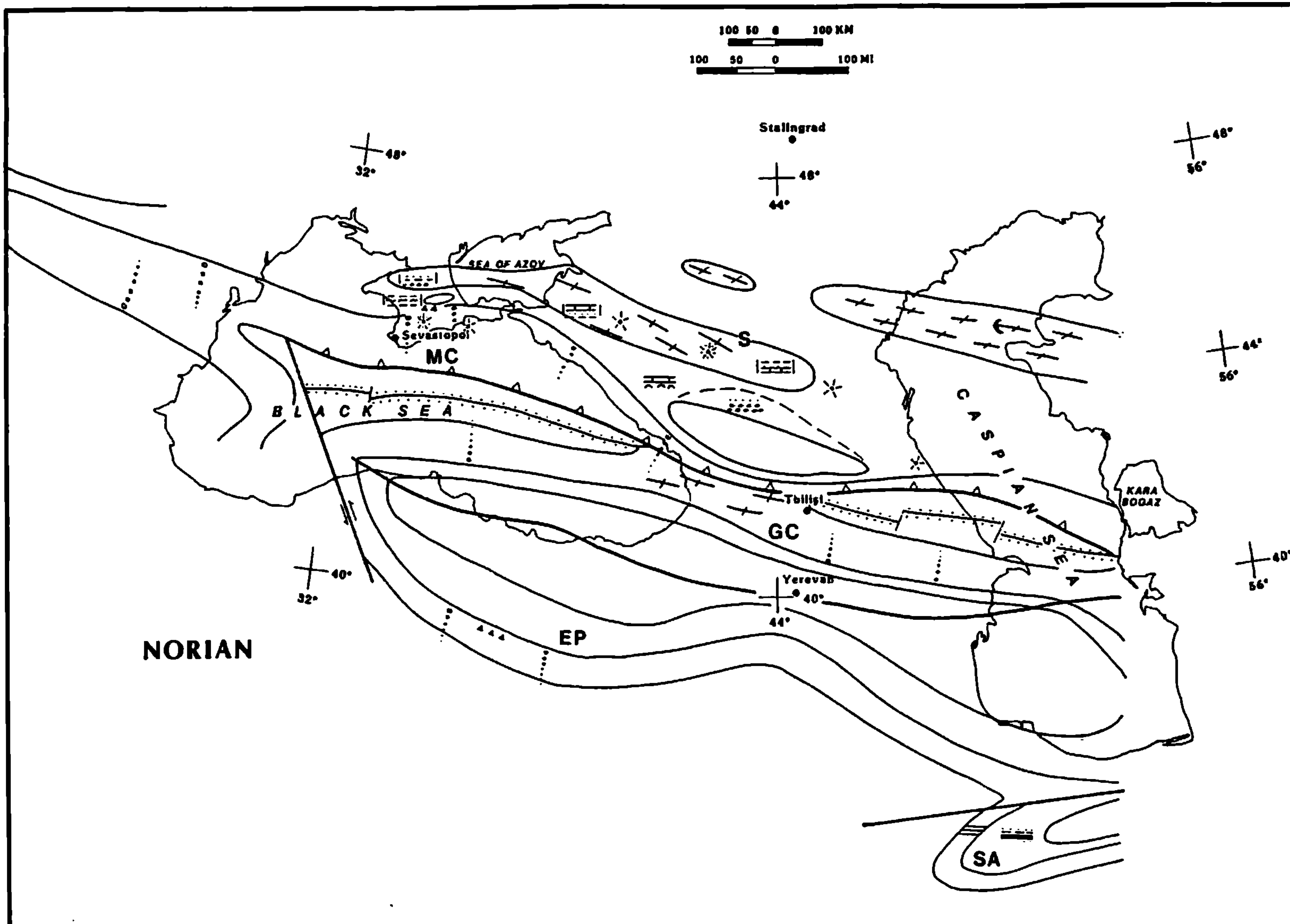

Fig. 3. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the Norian; see Map 2.

Pliensbachian (Map 3, Fig. 4)

The Triassic-Jurassic boundary is marked by an important reorganization of the oceanic realm, with the development of a new spreading pattern related to the changed kinematics of the major plates.

During the early-middle Liassic, subduction started beneath the Eastern Pontides (Sinemurian-Pliensbachian) and the Northern Transcaucasus (Hettangian-lower Pliensbachian). Only Toarcian acid volcanics alternating with limestones are known in the Southern Transcaucasus, but the base of this sequence has not been reached by drilling. On these blocks, pulses of volcanic activity alternate with shallow marine carbonate and terrigenous sediments. Abundant plant detritus in sediments indicates the proximity of numerous islands.

Behind the Pontian-Transcaucasian arc, the Greater Caucasian Sea expanded and deepened, and pelites and turbidites accumulated in it. The back-arc extension reached its maximum during late Domerian-Toarcian times when spreading was marked by MOR-type tholeiitic basaltic volcanism. After a period of turbiditic sedimentation, another phase of spreading occurred during the Aalenian. The Domerian-Toarcian and Aalenian spreading events coincide with a break in volcanic activity in the Transcaucasian arc. Paleomagnetic data indicate that the Northern and Southern Transcaucasian blocks were separated from each other by several hundred kilometers. The distance lies within the error of the method and could be disregarded but for the fact that all paleomagnetic measurements for the Mesozoic (Liassic to Upper Cretaceous) volcanic and sedimentary rocks performed by several researchers in different laboratories consistently point to separation of the Northern and Southern Transcaucasian blocks (Bathonian is the single exception). The paleomagnetic evidence is corroborated by paleovolcanologic evidence (Bajocian), paleobiologic data (Late Cretaceous), and some geophysics data. Still, the relationship between the Northern and Southern Transcaucasian blocks remains controversial; the contact between them is buried beneath the huge Paleogene wedge of volcanics and turbidites of the Adjara-Trialetian zone in the west and the young sediments of the Kura depression in the east.

If the existence of two separate Transcaucasian blocks is a reality, they could be either pre-Liassic or the result of Liassic spreading as shown on Map 3 (Fig. 4).

On the South Armenian block, a 200-meter-thick sequence of within-plate tholeiitic to mildly alkaline basalts and rhyolites lies disconformably over the Middle Triassic and grades upward into 300 meters of argillites and sandstones containing Toarcian to Aalenian ammonites. The volcanic episode seems to be related to rifting that affected the South Armenian block during the Early Jurassic.

In the Lower Jurassic and up to the Aalenian there is no clear distinction between the Boreal and the Tethyan faunal belts. North Tethyan (European) and South Tethyan (Gondwanian) faunal provinces can be recognized in the Eastern Mediterranean (Enay, 1976). The whole Caucasus (South Armenian block included), Pontides, Crimea, and the Eastern Carpathians belong to the European province. The boundary between the two provinces passes through the Erzincan ophiolitic suture south of the Pontides (Bassoullet *et al.*, 1975). A considerable faunal difference (on the generic level) between the Southern Transcaucasus and Southern Armenia (Rostovtsev and Azarian, 1971) implies that these two blocks of the European margin belonged to two separate basins of the Northern Tethys.

Bajocian (Map 4, Fig. 5)

In the Caucasian-Crimean part of Northern Tethys, the Bajocian was a period of extremely intense volcanic activity along the active margins. A 3-km-thick pile of arc-type volcanics was formed in the Transcaucasus. There are two distinct volcanic fronts in the Southern and Northern Transcaucasus. The Southern Transcaucasian volcanic front is characterized by boninitic to arc-type tholeiitic volcanism, which implies that part of the Southern Transcaucasian arc was ensimatic. The lower part of the Northern Transcaucasian volcanic pile is built up of arc-type tholeiitic basalts and basaltic andesites which pass, high in the section, to calc-alkaline and finally to high potash calc-alkaline and shoshonitic volcanics. These seem to have formed mainly on sialic basement. The differing evolutionary trends may be indicative of two separate arc segments.

The existence of the two Bajocian volcanic fronts in the Transcaucasus points to the existence of two independent Northern and Southern Transcaucasian arc segments. According to paleomagnetic evidence, these segments were separated by 5-7°. Two *en echelon* segments or a double chain of volcanic arcs may be accepted (Map 4, Fig. 5), but the assumption is provisional because the presence of a suture zone between the two has not been proved.

In both the Northern and Southern Transcaucasian arc segments, the distribution of sediments is controlled by the distribution of the submarine and subaerial volcanoes. Volcaniclastic material was removed from the slopes of the

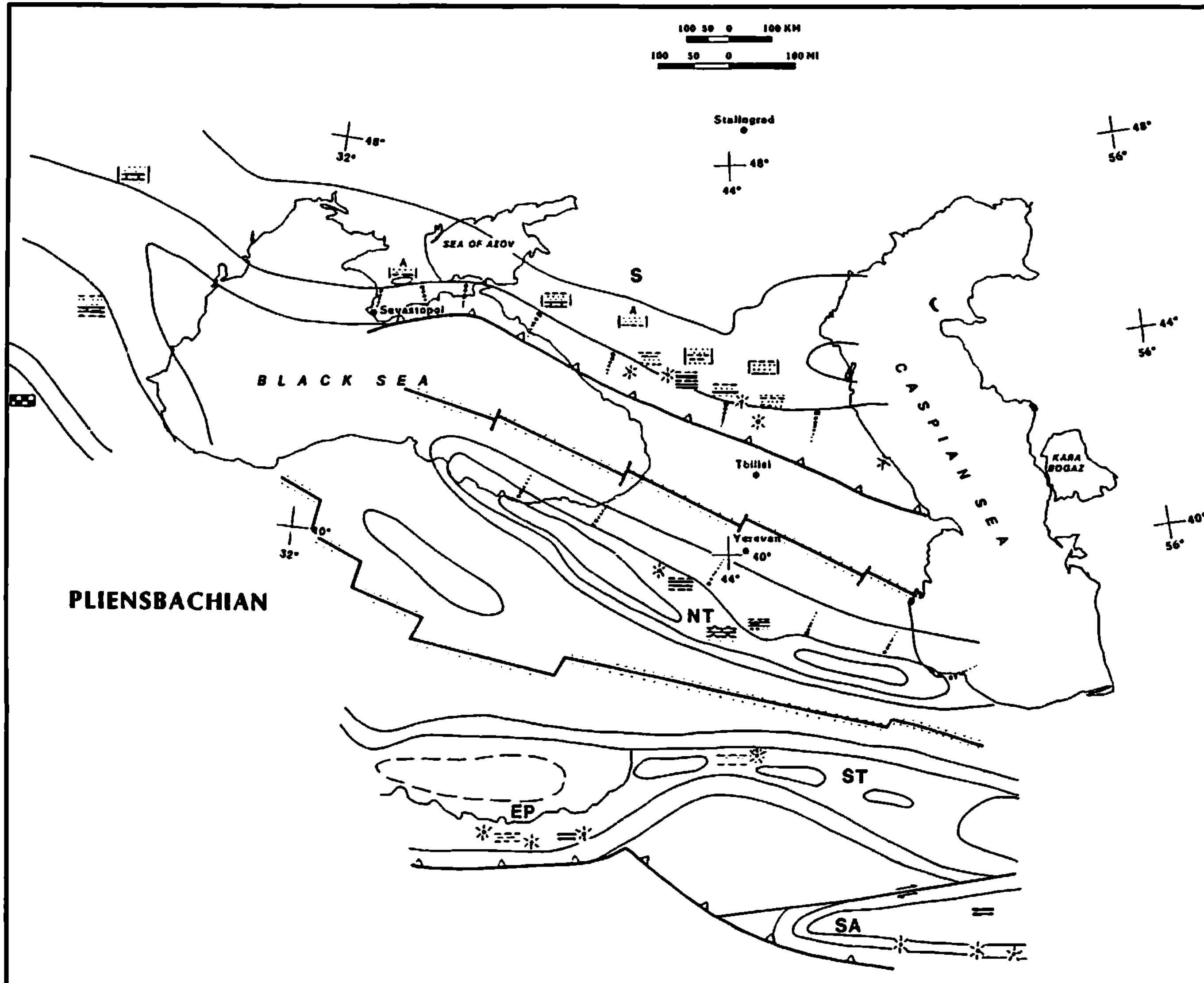

Fig. 4. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the Pliensbachian; see Map 3.

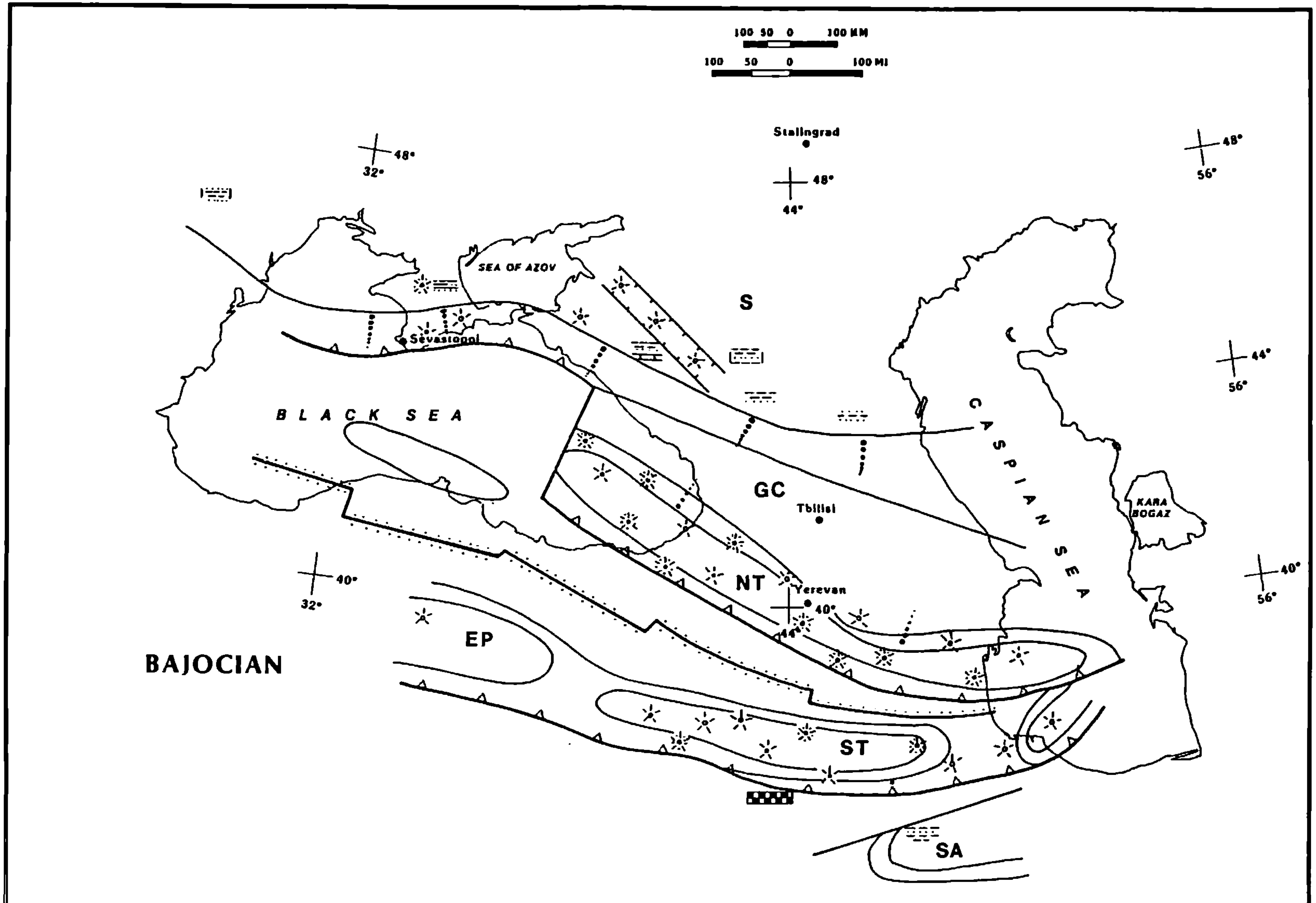

Fig. 5. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the Bajocian; see Map 4.

volcanoes by turbidity currents and redeposited between the volcanic edifices as well as transported south into the fore-arc basin and north into the back-arc basin (Beridze, 1983). A northward deepening basin was established north of the North Transcaucasian arc segment and a narrow band of volcaniclastic flysch 2 km thick extended along its southwestern margin. These Bajocian volcanics are shallow-marine to subaerial along the southeastern periphery. It must be stressed that the southernmost part of the Northern Transcaucasus was buried to a depth exceeding 6 km below the present surface of the Rioni (Kolkhis) depression, and probably even deeper, by thick Cretaceous to Paleogene volcanics and turbidites of the Adjara-Trialetian zone. Here, the Bajocian levels have not yet been penetrated by drilling, and thus the relationship between the Northern Transcaucasian and East Pontian/Southern Transcaucasian Middle Jurassic assemblages remains obscure.

The subduction-related Bajocian volcanics of the westernmost pre-Caucasus and Mountainous Crimea evidently represent an Andean-type segment of the North Tethyan active margin. This segment was delimited to the east by a fault-zone marked by a chain of volcanoes from which erupted within-plate type alkaline basalts. Bajocian volcanics are not known as yet in the Eastern Pontides, but along the northern margin of the Central and Western Pontides, the Küre ophiolitic formation is crowned by the Middle Jurassic acid volcanics. These may indicate southward subduction beneath the Pontides as shown in Map 4 (Fig. 5).

Volcaniclastics continued to accumulate in the Greater Caucasian Basin to the south, with terrigenous turbidites in the central part. The latter grade northward into shallow marine, sandy-argillaceous deposits and limestones of the Scythian shelf.

The important Bathonian tectonic activity resulted in regression which greatly reduced the Crimea-Caucasian marine basins. The sea retreated from the major part of the Scythian shelf and from the Northern Transcaucasus and, over the resulting landscape, coal swamps developed under favorable climatic conditions as the shallow sea passed into lagoons, swamps, and limnic and paralic basins. Consequently, important coal deposits are found in the Bathonian of the Northern Transcaucasus.

In the southern and northern parts of the Greater Caucasian deep-marine basin, the sedimentary cover was deformed and intruded by gabbroic to granitic plutons. The basin itself was subdivided into western and eastern deep-marine troughs, connecting over a central shallow-marine arch. Coarse turbidites continued to accumulate in these troughs.

In the Southern Transcaucasus, the upper Bajocian volcanic and sedimentary deposits are followed by littoral-marine and continental coal-bearing Bathonian sandstones and argillites. The latter locally incorporate thick andesitic volcanics. Granitoid intrusions occurred in both the Northern and Southern Transcaucasus.

Callovian (Map 5, Fig. 6)

In the Caucasus, the Callovian started with transgression. The sea expanded from the Greater Caucasian deep-marine basin to the north, covering the southern parts of the Scythian platform and, to the south, over the Northern Transcaucasus.

In the western and eastern flysch basins of the Greater Caucasus, the sandy-argillaceous sedimentation of the Bathonian was followed by an accumulation of thin, clastic, and sparitic limestones. On the Scythian shelf and in the Northern Transcaucasus, the Callovian deposits are mainly sandstones and conglomerates, followed by littoral, sandy limestones. They are transgressive over different horizons of the Middle and Lower Jurassic. From late Oxfordian to early Tithonian times, small reefs (rhythmobiotects) repeatedly built up along the northern and southern margins of the Greater Caucasian flysch basins (Bendukidze, 1978). East-west barrier reefs developed north of the northern flysch-reef zone and south of the southern flysch-reef margin. These are characteristic epicontinental barrier-reefs with an abundant *Nerinea* and diceratid fauna. Lagoons with sandy-argillaceous sediments and evaporites — halite, anhydrite, and important gypsum deposits — developed behind these reefs, on the Scythian Platform and in the Northern Transcaucasus.

Intense within-plate basaltic volcanism of the Rioni (Kolkhis) and Kura depressions persisted until the early Tithonian, with active subduction under the Southern Transcaucasus and Eastern Pontides. Here, arc-type tholeiitic and calc-alkaline volcanics alternate with carbonates. In contrast to the Northern Transcaucasus, halite is absent and, although dolomites are widespread, gypsum occurs only locally. It must be emphasized that in a few localities in the Southern Transcaucasus, Callovian and Oxfordian sediments are transgressive over a strongly tectonized serpentinitic mélange (southern Georgia) or over basalt-radiolaritic ophiolite assemblages (Azerbaijan). The basement of these rocks of ophiolite affinities is not exposed. Pre-Upper Jurassic ophiolite obduction, comparable to the Küre ophiolite obduction in the Pontides (Yilmaz and Sengör, 1985) or

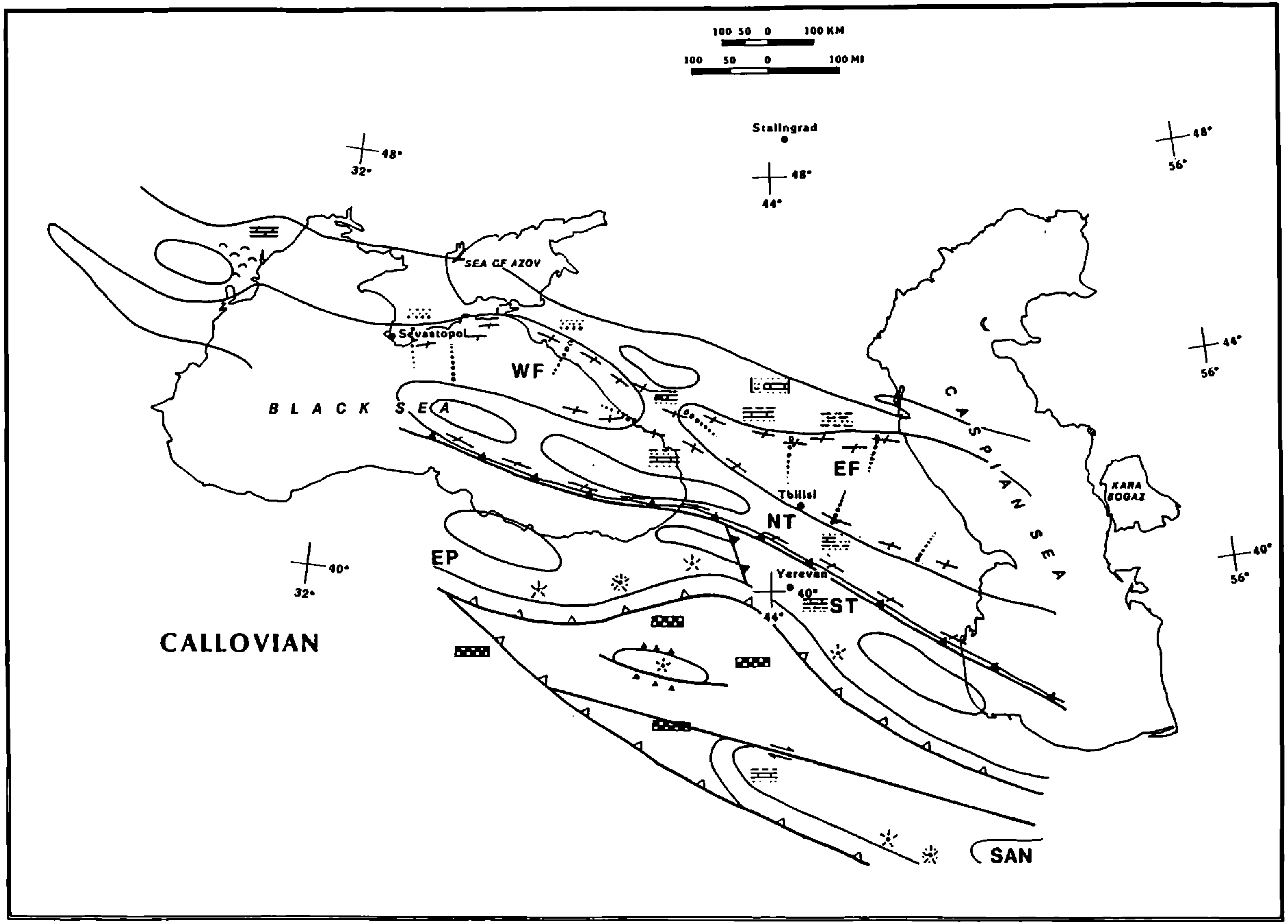

Fig. 6. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the Callovian; see Map 5.

the Late Jurassic transgression over uplifted blocks of oceanic basement in the Southern Transcaucasian arc segment are equally possible.

The Mediterranean (Tethyan) faunal belt was reduced to the Carpathian-Pamirs zone by a major invasion of Boreal forms in the Late Jurassic. The northern limit of the Upper Jurassic corals passes through Yorkshire-Hannover-Krakow-Grozni and this line coincides in general with the boundary between the Tethyan and Boreal belts.

Tithonian (Map 6, Fig. 7)

There were no significant paleogeographic changes during the Tithonian. Carbonate turbidites continued to accumulate in the Greater Caucasian flsych basins. Both sides of these basins are delimited by barrier reefs, which separate them from the Scythian carbonate shelf in the north and from the North Transcaucasian carbonate shelf to the south. The North Transcaucasian shallow-marine limestones grade southward into sandy-argillaceous variegated sediments with halite and anhydrite layers. Within-plate basaltic volcanism of the Kolkhis and Kura depressions persisted until the early Tithonian, basalts alternating with evaporites (in the west), and carbonates (in the east). Subduction under the Southern Transcaucasus Pontides remained active. Spreading in the Lesser Caucasus part of the Tethys is indicated by presence of MORB-type tholeiitic basalts in the Lesser Caucasian ophilites. A chain of oceanic islands and seamounts or a leaky transform fault brought within-plate type alkali basalts to the surface. The presence of tholeiites can also be inferred from the evidence of the ophiolites.

Barremian (Map 7, Fig. 8)

There were no significant changes in paleogeography during the Barremian. On the southern shelf of the Scythian Platform (pre-Caucasus, Northern Caucasus) Lower Cretaceous sedimentation is marked by the development of sandy-argillaceous facies with carbonate intercalations which became important and even dominant in the southernmost part of the area. A Valanginian Urgonian facies is recorded. Repeated sea level fluctuations are reflected by a reduced section with numerous breaks in the succession. Thus, the pre-Caucasus-Northern Caucasus may be regarded as an unstable platform with several internal and external portions along its southern periphery. In the Crimean part of the Scythian platform, the lowermost Cretaceous sequence consists of terrigenous carbonate and cherty beds. A brief precursory interlude of carbonate sedimentation during Berriasian times interrupted the silty-sandy sequence. This was followed, during the Valanginian, by the establishment of biogenic carbonates with massive biohermal Urgonian limestones, which spread throughout the Crimea, indicating the existence of an extensive neritic platform over which littoral conditions were established in both northern and southern (Mountainous) Crimea. However, a clay facies with siderite concretions predominated in late Valanginian time and until the end of the Aptian. These shallow marine deposits indicate an abundant supply of clastic materials. Sandstones (sometimes quartz-glauconitic), aleurolites, gritstones, and conglomerates are present in some places; in others, local bioclastic limestones with cephalopods mark intervals of clearer water sedimentation within a generally argillaceous environment.

Carbonate and argillaceous sedimentation continued without interruption from Late Jurassic time in the eastern and western flysch basins of the Greater Caucasus. In the western basin, the Upper Jurassic-lower Valanginian carbonate-detrital sequence is followed by upper Valanginian-lower Aptian sideritic argillites. The succession differs in the eastern basin; the carbonates persisted longer (up to lower Hauterivian) and were followed by terrigenous flysch (upper Hauterivian to top Albian).

The Early Cretaceous transgression in the Northern Transcaucasus progressed from north to south, marked by deposition of Berriasian quartz sandstones and conglomerates derived from the northwest, gradually younging as the transgression encroached southward over the Dzirula massif, where they are dated as Barremian. The rapid subsidence in the north resulted in deposition of infra-neritic laminated limestones during Valanginian-Barremian times. The Urgonian facies is missing. A shallow littoral sea existed over the major part of the Northern Transcaucasus during Valanginian-early Barremian times. The presence of dinosaur footprints near the Sataplia Karst cave points to sea level fluctuations near coastal areas. Evidence of littoral conditions is also preserved in the Hauterivian where Urgonian shelf limestone conditions affected the major part of the Northern Transcaucasus. The Urgonian facies persisted into the Barremian but had mostly ended by the end of the early Barremian, when renewed subsidence led to the deposition of epineritic, ammonite limestones as the Northern Transcaucasus subsided. During Aptian time, uniform marly limestones spread over the entire Northern Transcaucasus.

In the Southern Transcaucasus-Eastern Pontides, arc-type volcanic activity gradually diminished and volcanic rocks alternate with shallow-marine carbonates. Only weak and very local

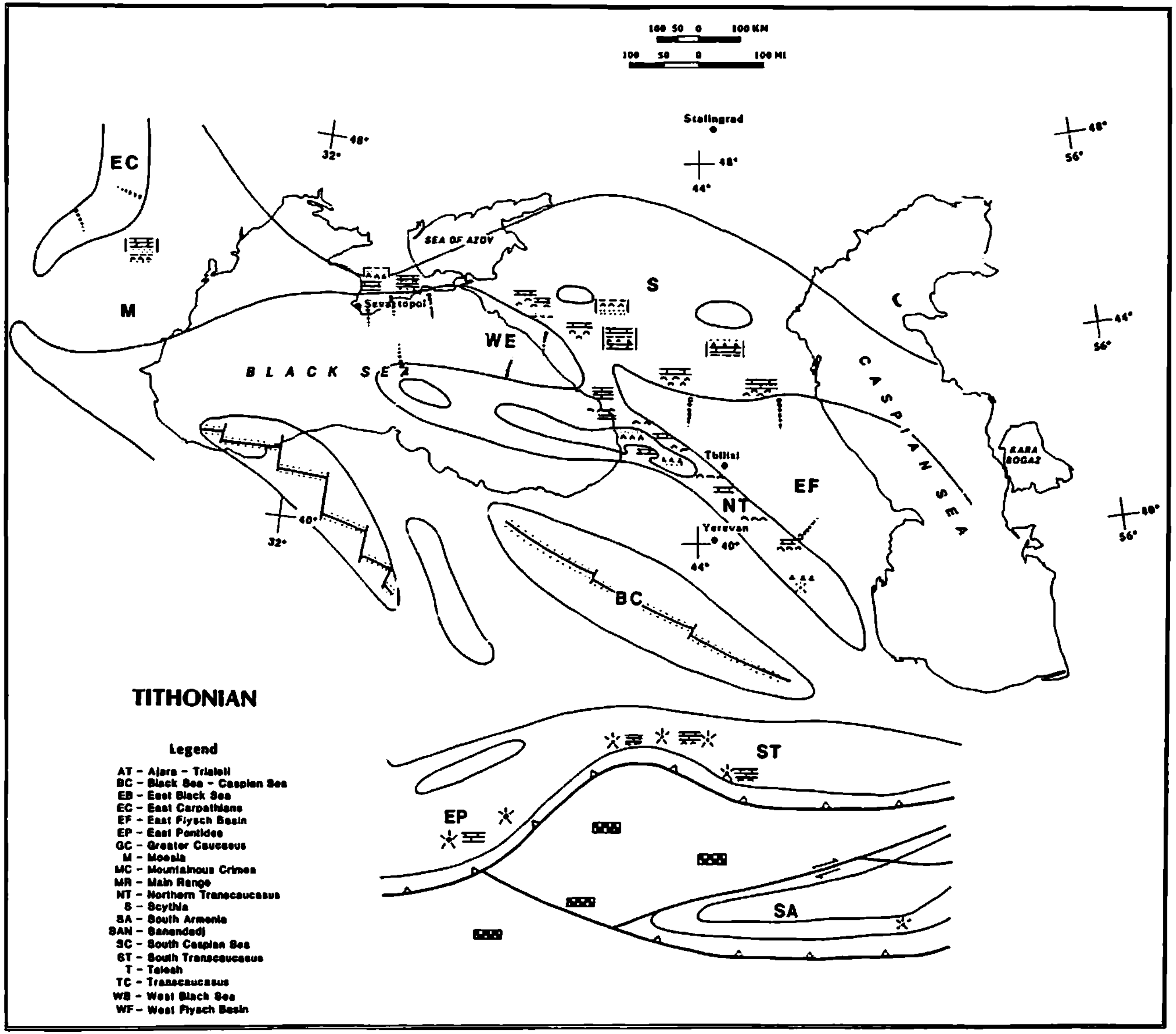

Fig. 7. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the Tithonian; see Map 6.

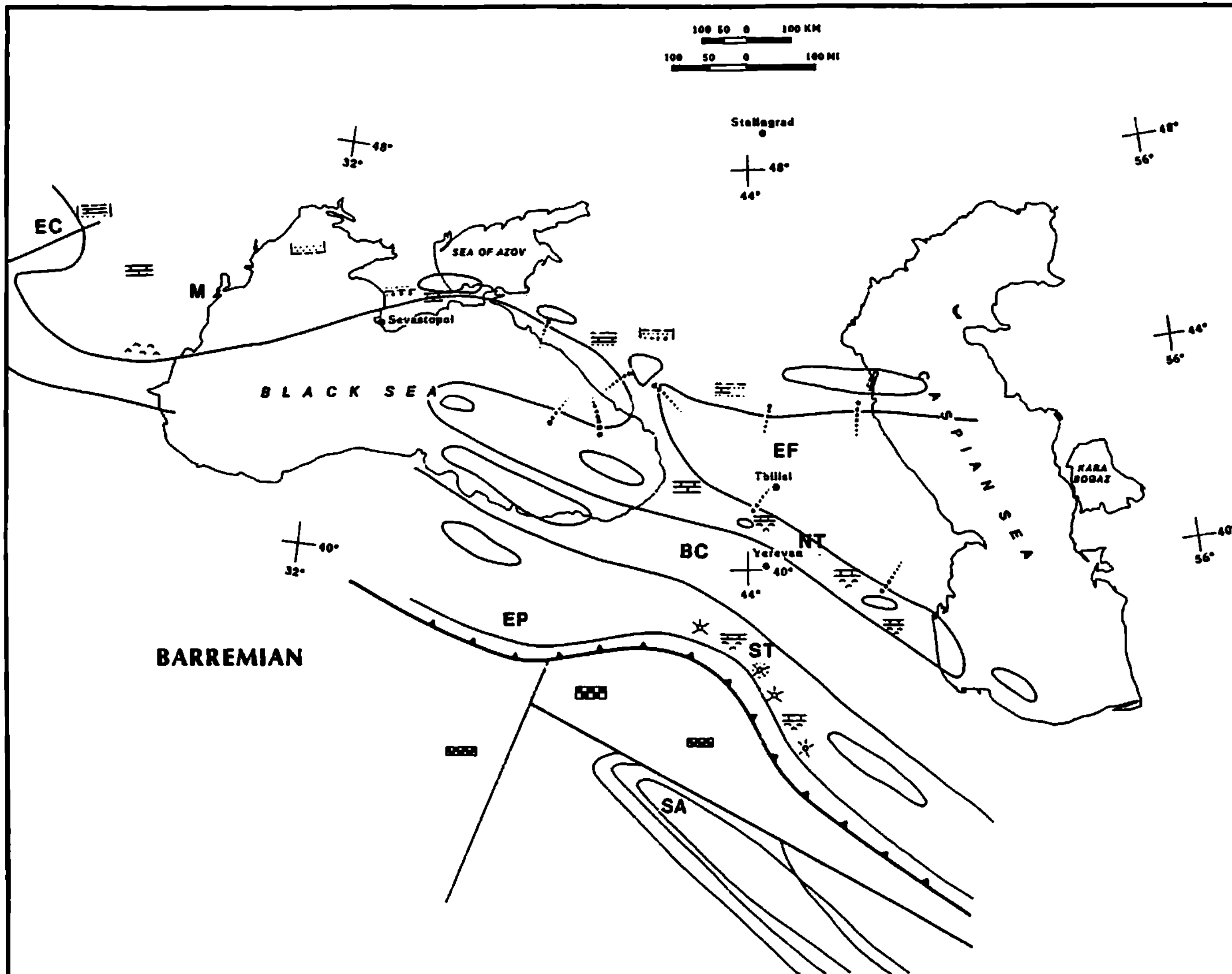

Fig. 8. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the Barremian; see Map 7.

manifestations of volcanic activity are recorded in the Valanginian. Urgonian limestones were deposited from late Valanginian time and are widespread in the Barremian. The within-plate type tholeiitic to mildly alkaline basalts that alternate with limestone in the northeastern part of the unit (Kura depression) are assigned to back-arc rifting.

Evidence from the Lesser Caucasian ophiolites points to spreading and within-plate type volcanism in the Lesser Caucasian part of Tethys during the early Neocomian. Barremian basalt-radiolaritic sequences are not known here.

The Upper Jurassic-Lower Cretaceous sequence is lacking in southern Armenia, which implies an important period of denudation prior to the Cenomanian.

From the beginning of the Early Cretaceous, the boundary between the Tethyan and Boreal realms, marked by the northern limit of the coral occurrence, was displaced south of a line passing through Paris-Krakow-Simferopol-Baku. Brachiopods and bivalves decrease markedly north of this line. The Alpine-Caucasian district of the Mediterranean province can be distinguished; the western part is characterized by the presence of Gondwanian genera that penetrated as far east as the Crimea. In the eastern part, a Boreal influence was increasingly important from Berriasian to Valanginian time and was still quite considerable in the Hauterivian when the Northern Caucasus was transitional between the Boreal and Tethyan realms and Boreal forms penetrated into the Northern Caucasus and Crimea (Kotetishvili, 1983). In the Barremian, a typical Mediterranean ammonite complex became established all over the Crimea, Caucasus, and Carpathians. The Boreal influence, so strong in the preceding periods, had little significance in the Barremian. With the equalizing of conditions between the Tethyan and Boreal realms during the Aptian, ammonite provincialism was considerably reduced.

Albian (Map 8, Fig. 9)

The Albian paleogeography of the northern part of the region is very similar to that of the Neocomian. Terrigenous sedimentation continued in the pre-Caucasus and Northern Caucasus. Marl intercalations of middle-late Albian age are precursors of the intense carbonate sedimentation that occupied all of the Late Cretaceous. Argillites containing sideritic concretions persisted in the Albian of the Crimea, although local shallow-marine limestones did occur. Arc-type andesitic volcanism developed in the Crimea-western pre-Caucasus — *i.e.*, in the southwestern part of the Scythian platform.

In the western flysch basin of the Greater Caucasus, a middle-upper Aptian glauconitic and carbonate sequence passed upward into lower Albian sideritic argillites. In the eastern basin, terrigenous flysch continued to accumulate throughout the Albian.

Uniform marly limestones and marls were deposited in the Northern Transcaucasus. The bathymetric distinction between the northern and southern parts of the unit disappeared. Arc-type tholeiitic basalts and basaltic andesites formed locally, pointing to renewed subduction under the Northern Transcaucasus.

Aptian-Albian deposits are absent over the major part of the Southern Transcaucasus. Only along the southeastern margin of the area were terrigenous turbidites (argillites, sandstones, and marls) deposited — evidence of a rapid subsidence. The first input of fine clastic, ophiolitic material into the southern Transcaucasian basin is recorded for Albian time (Knipper, 1980).

An oceanic island arc formed in the Lesser Caucasian branch of Tethys. Albian to Turonian arc-type boninitic-tholeiitic volcanics and radiolarites with wedges of reef limestones are preserved within the Lesser Caucasian ophiolitic belt (Knipper *et al.*, 1985). Similar processes occurred all over the Eastern Tethys and seem to be related to the renewed convergence of the African-Arabian and European plates.

Within-plate type continental alkaline basalts and trachytes of presumed Albian age are recorded along a narrow NW/SE-trending belt in the South Armenian block. These volcanics closely coincide in space with Lower Jurassic within-plate type basalts and seem to be related to activity along the same fault. A westward extension of the latter is conditionally assumed.

Coniacian (Map 9, Fig. 10)

During the Late Cretaceous, clastic input diminished over the entire southern shelf of the Scythian platform (pre-Caucasus, Northern Caucasus, Crimea). A marly limestone facies prevailed in the pre-Caucasus and Northern Caucasus. The basal part of the Crimean Upper Cretaceous is represented by an alternation of sandstones and conglomerates with thick limestones and marls. These deposits rest unconformably on sediments ranging from Albian to Middle Jurassic in age. Arc-type volcanic activity along the southwestern margin of the Scythian platform (Crimea, western pre-Caucasus) persisted until the Cenomanian.

Turbidity currents deposited a rhythmic sequence of marls, limestones, and siltstones in the western flysch basin of the Greater Caucasus, as well as in extreme southeastern Crimea. The basal

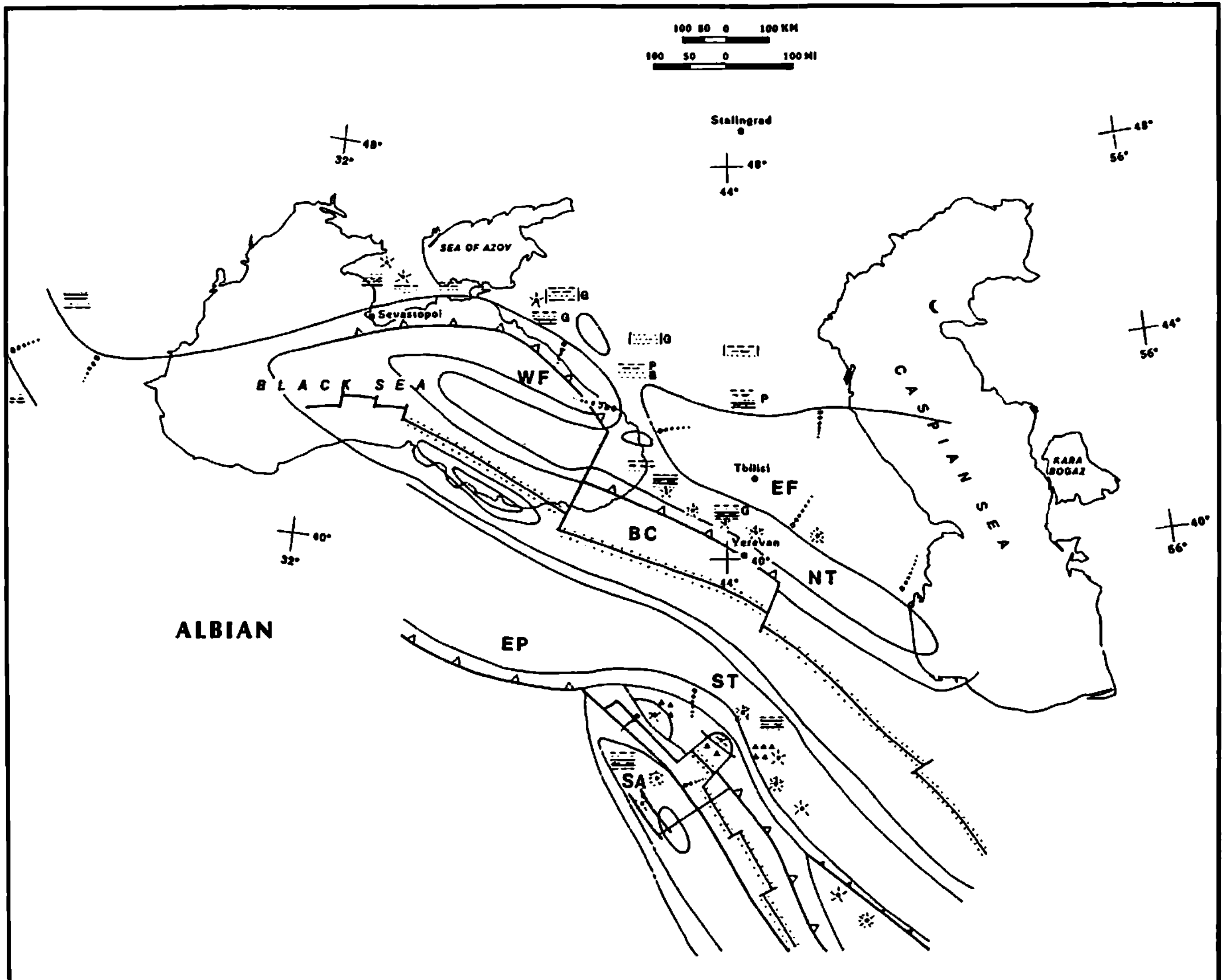

Fig. 9. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the Albian; see Map 8.

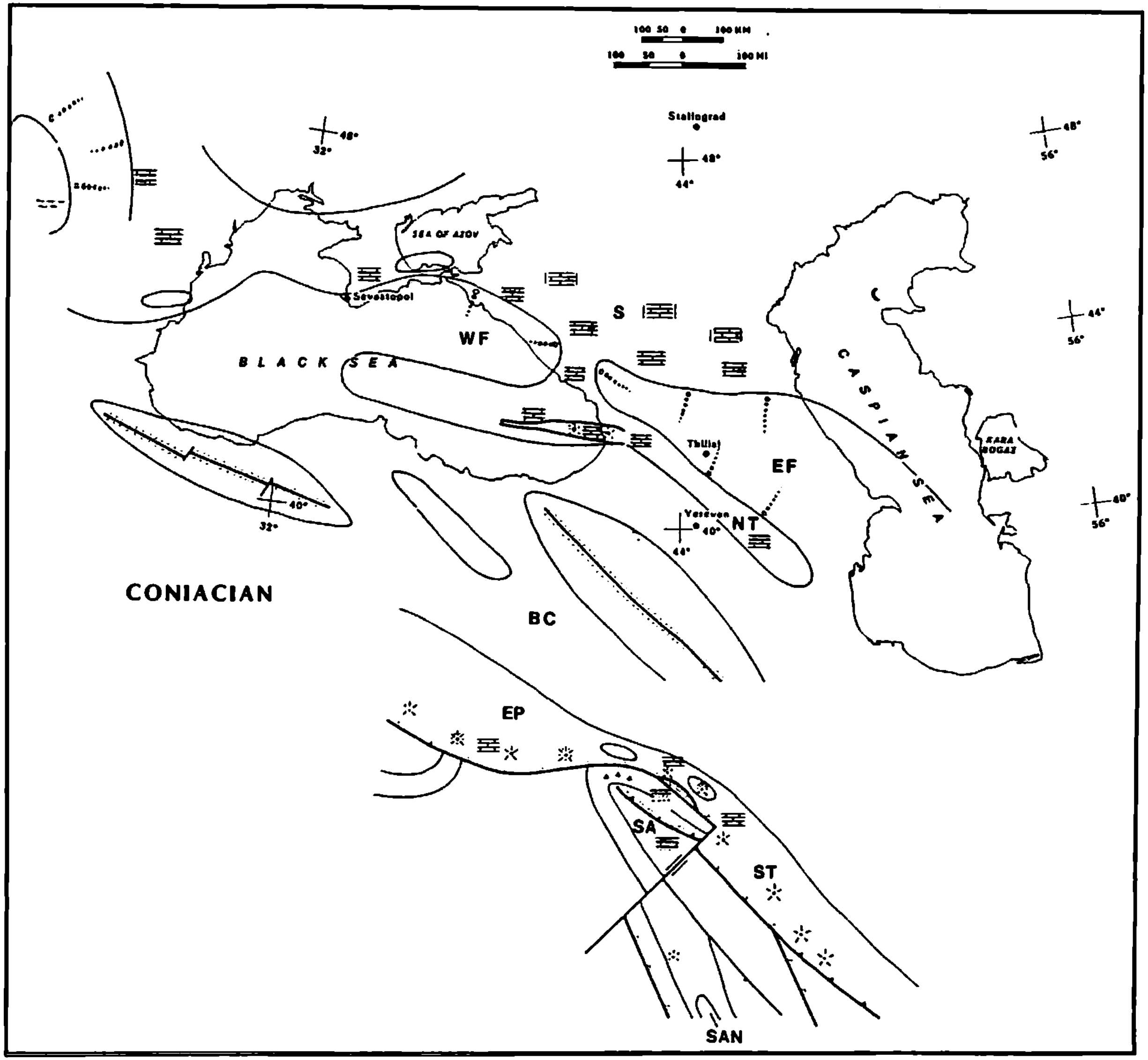

Fig. 10. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the Coniacian; see Map 9.

Cenomanian part of this sequence contains cherts and argillites. In the eastern flysch basin, terrigenous-cherty deposits of Cenomanian age are followed by clastic limestones deposited during the Turonian-Senonian. Olistostrome wedges occur in the Maestrichtian succession.

In the Northern Transcaucasus, the Late Cretaceous began with a major transgression as terrigenous-volcaniclastic sediments of the Cenomanian-early Turonian were progressively replaced by carbonate sedimentation as the sea deepened. The sequence contains several levels of chert concretions.

In the Pontides-Southern Transcaucasus, arc-type volcanic activity began in the Cenomanian and persisted until the Santonian. Volcanic pulses alternated with periods of carbonate sedimentation. Terrigenous turbidites continued to accumulate along the southernmost part of the Southern Transcaucasus, accompanied by huge ophioliticclastic olistostromes from late Cenomanian time up to the early Coniacian.

Major changes during the mid-Coniacian affected the southern part of the region; oceanic crust was obducted over the Southern Transcaucasian arc and over the South Armenian block. This obduction predates the major Tethyan ophiolite obduction of Campanian-Maastrichtian time, and many authors relate this local obduction event to the collision of the South Armenian block with the Southern Transcaucasian arc.

Shallow-marine carbonate sedimentation predominated in the Southern Transcaucasus as well as in the South Armenian block during the late Coniacian. Arc-type volcanism persisted in the Southern Transcaucasus until Santonian time, although local manifestations of Campanian-Maestrichtian volcanism are known in the southeastern margin of the unit, in the ophiolitic suture. The Campanian-Maestrichtian volcanic sequence is characterized by an alternation of within-plate type basalts and trachyandesites with arc-type andesites and shoshonites. These may, in part, be related to a post-collisional tensional event. Manifestations of Campanian-Maestrichtian volcanism are very important in the Pontides, but data on their composition are not available.

Paleocene (Map 10, Fig 11)

In the Crimean plain and the pre-Caucasus, as well as in the Northern Transcaucasus, the uniform deposition of shallow marine marls and limestones is characteristic of the Paleocene. Marly turbidites accumulated in the remnant eastern and western flysch basins of the Greater Caucasus, as well as in the East Carpathians.

The Pontides-Southern Transcaucasus-South Armenian block, as well as the Alborz and Central Iran, was part of a complex Tethyan island arc system characterized by mainly calc-alkaline volcanism and local tholeiites. The South Armenian segment of this arc may have been situated at least 100 km east of its present position, for several authors suggest an important post-Eocene westward shift of this unit along the Lesser Caucasian ophiolitic suture. Thick (up to 2000 m) terrigenous flysch accumulated behind the volcanic arc, in the Adjara-Trialetian and Talysh back-arc basins. The Talysh turbiditic sedimentation was accompanied by eruption of K-rich basalts and basanites. The basaltic crust of the eastern Black Sea and the southern Caspian may have been formed during this back-arc rifting event.

Eocene (Lutetian; Map 11, Fig. 12)

During mid-Eocene times, the shallow-marine basins of the Crimea, pre-Caucasus, and Northern Transcaucasus accumulated clastic and biogenic, often nummulitic, carbonates. Coarse turbidites are found in the East Carpathian and Greater Caucasian basins. the mid- to upper Eocene marly turbidites of the Greater Caucasus contain huge olistostromes (wildflysch), indicating the increased intensity of deformation and overthrusting. In the Pontian-South Armenian-South Transcaucasian island arc, intense volcanic activity seems to be related to accelerated convergence of the African-Arabian and European plates and to a rapid subduction of oceanic crust in the remnant Tethyan basins. The geochemical signature of the Eocene arc volcanics (mainly high-K calc-alkaline and shoshonitic to ultrapotassic series) is indicative of continental sediment involvement in the petrogenetic processes, probably through their subduction during the pre-collisional and collisional stages of development (Lordkipanidze *et al.*, 1989, Volume II of this series).

Middle-Upper Oligocene (Map 12 Fig. 13)

Late Alpine neotectonic development began in the Oligocene. The deep marine flysch basins of the southern slope of the Greater Caucasus began to invert, but the relief of the newly formed, discontinuous landmasses was still low; hence, the sediment supplied to the neighboring basins consisted of thin clastic material. The only relict flysch basin, in the East Carpathians, survived up to the beginning of the Miocene. A euxinic, deep to shallow sea covered large parts of the region. Extremely monotonous, sandy, argillitic sediments with gypsum and jarosite (Maikopian series) indicate anaerobic depositional conditions. These

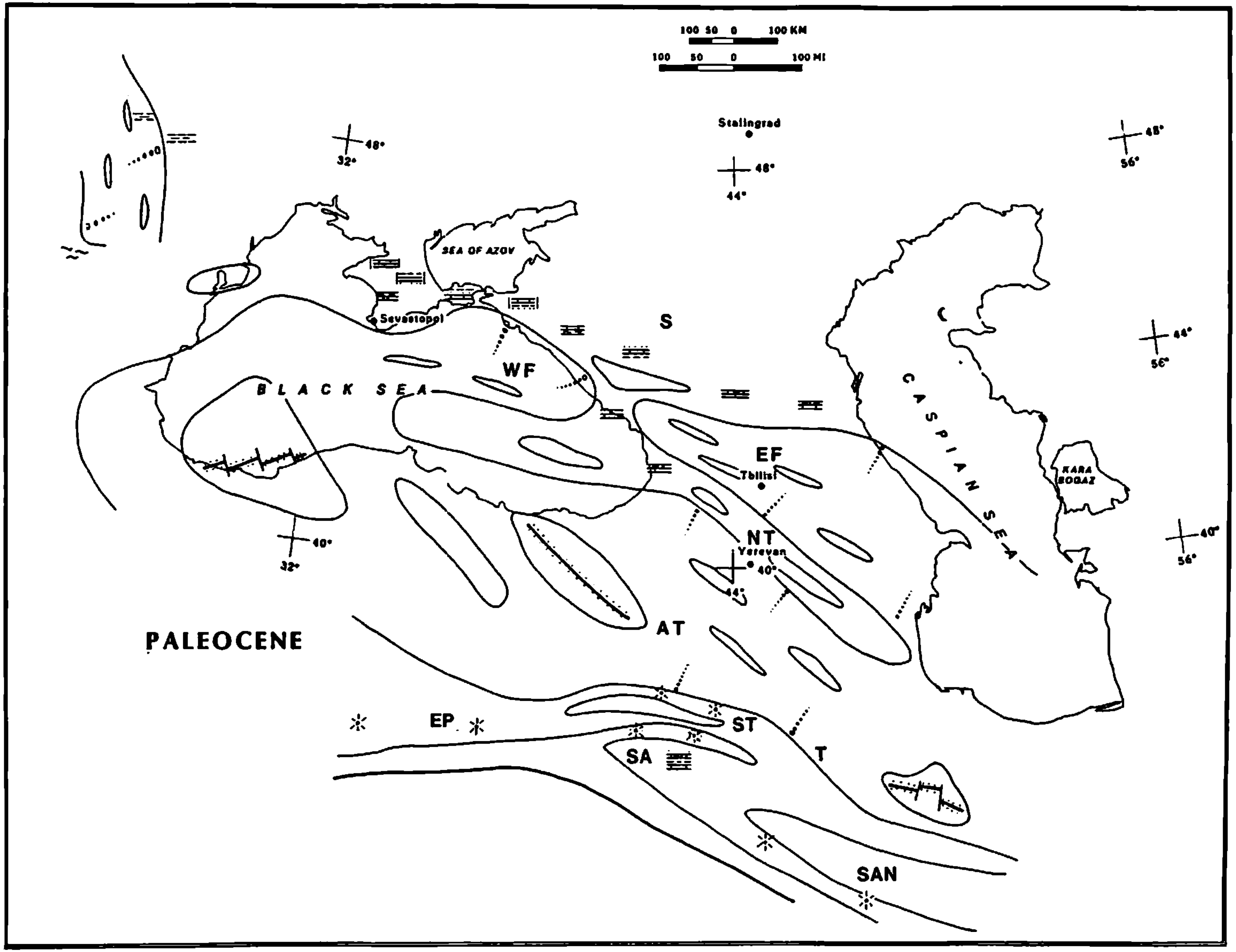

Fig. 11. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the Paleocene; see Map 10.

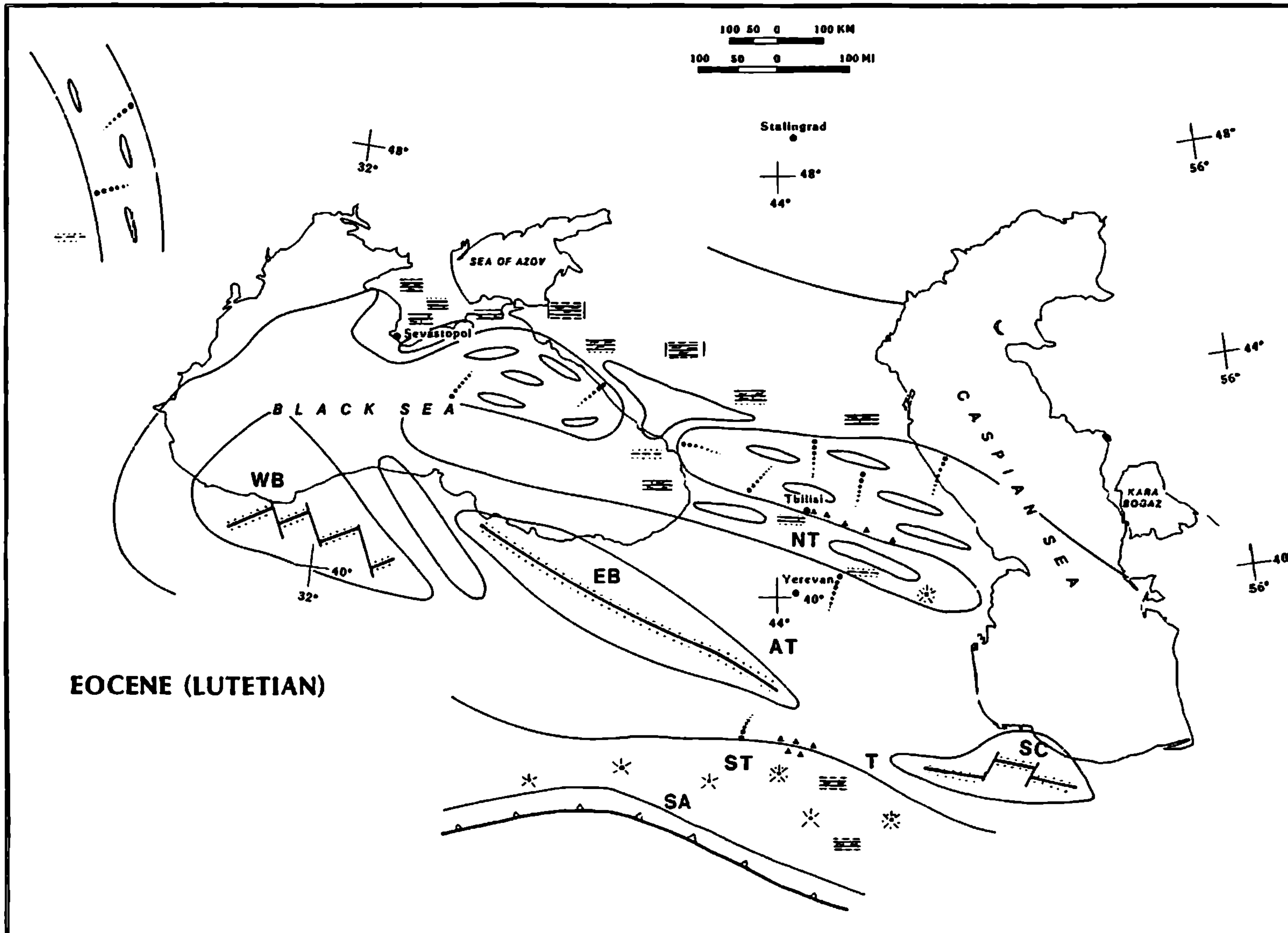

Fig. 12. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the Eocene (Lutetian); see Map 11.

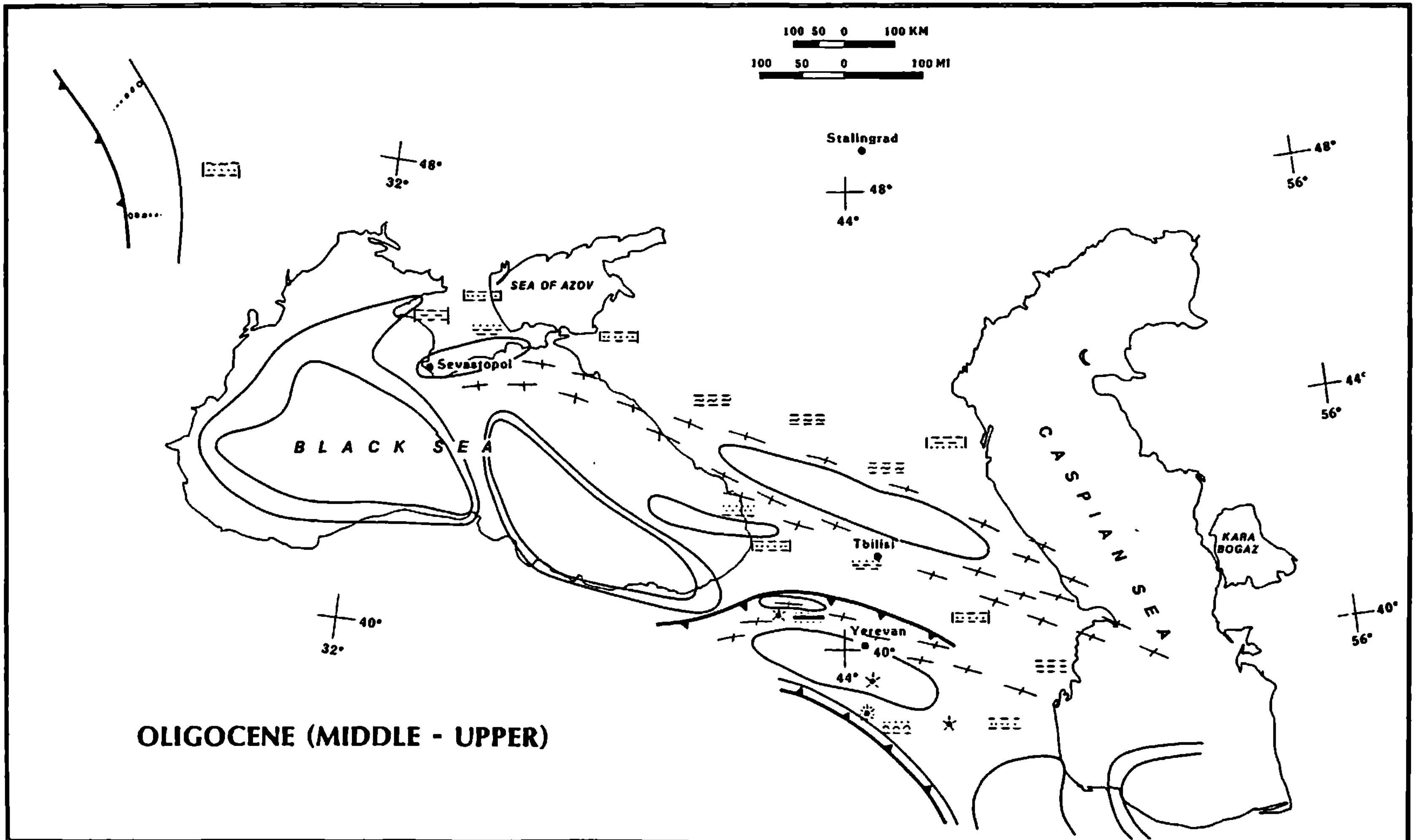

Fig. 13. Paleogeographic map of the Ukrainian Carpathians, the Crimea, and the Caucasus during the middle upper Oligocene; see Map 12.

facies and the remains of deep marine fish indicate that the deepest parts of the sea lay in both the southern part of the Rioni (Kolkhis) depression and the Northern Caucasus. The facies and the faunal similarities between these areas imply the existence of a long, deep trough connecting them.

The Adjara-Trialetian lower Oligocene is characteristic of a prograding continental slope bordered on the south by the Rioni trough. The South Trancaucasian lower Oligocene consists of comparatively shallow marine deposits — coral reefs in Armenia and deposits of brown coal in southern Georgia.

In the middle upper Oligocene, the wide distribution of coarse sandstones and conglomerates suggests the appearance of mountains in the Greater and Lesser Caucasus. In southern Armenia and Iran, local volcanism is characterized by association of high-Ti alkaline, within-plate basalt-trachytes and low-Ti shoshonites. The volcanism was accompanied by granitic and syenitic intrusive activity, which seems to be related to transverse faulting during the collision with the faults, bringing to the surface melts from deep mantle sources as well as water-enriched magmas from shallower remnants of subduction-generated magma chambers.

CONCLUSION

The Paleozoic-Mesozoic history of the Crimea-Caucasian region can be interpreted as evolution of a Western Pacific type active margin (Adamia *et al.*, 1977) comprising Andean-type volcanic arcs as well as oceanic to ensialic island arc/back-arc systems. Major stages of the reorganization of Tethyan plate kinematics coincide in time with the restructuring of the Crimea-Caucasian active margin; pre-existing island arc/back-arc pairs were deformed, disrupted, and partly accreted to the European shelf simultaneously with the birth of the new island arc/back-arc systems.

Toward the Late Triassic, and probably earlier, the South Armenian fragment of Gondwana had been transported to the northern margin of Tethys. The middle Coniacian ophiolite obduction onto the Southern Transcaucasus and southern Armenia is interpreted as a result of the collision between the Southern Transcaucasian arc segment and the South Armenian terrain. Beginning in the Paleocene, the latter was part of the North Tethyan island arc system. An important lateral shift of this terrain in the Mesozoic is implied, but the direction and scale of this displacement remain obscure.

The character of the geologic development of the Caucasian-Crimean part of the Eastern Mediterranean, as well as reconstructions of the major plate positions during the Paleogene (Savostin *et al.*, 1986), indicate a narrow oceanic space between Africa-Arabia and Eurasia, with an extensive island arc system along its northern margin. This may be comparable to the present-day island arc/back-arc pairs of the Mediterranean Sea.

The Cretaceous-Neogene flysch basins of the East Carpathians represent northern marginal basins of a narrow Western Tethys, where subduction seems to be important only in the early Mesozoic. We emphasize that even if the major evolutionary trend of the Crimean-Pontian-Caucasian part of the Tethys seems to be well established and many important details of Tethys seem to be well established, important details of this evolution remain highly controversial or obscure.

Widely divergent interpretations exist of the relationship of the Paleozoic and Mesozoic oceanic basins, the origin of the Dizi series, and the Paleozoic to early Mesozoic position of the Pontides and Transcaucasus. Further detailed structural, paleontologic, and sedimentologic studies of the Dizi series of the Greater Caucasus and of the Küre ophiolites of the Northern Pontides, as well as paleomagnetic studies of the well-dated Paleozoic and Mesozoic rocks of the Pontides and the Transcaucasus, are of major importance for a better understanding of the above problems. Also, our present knowledge of the deep crustal structure of the Crimea-Pontides-Caucasus is less than that of the Alps and Carpathians. International programs to combine deep crustal geophysical studies with deep drilling on land as well as in the Black and Caspian Seas are required to assess relationships between the Pontian and Northern and Southern Transcaucasian parts of the region, as well as the age and origin of the basaltic crust of the Black Sea and the southern Caspian Sea.

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