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A review of the stratigraphy of Eastern Paratethys (Oligocene–Holocene)

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Synopsis. All available data pertaining to the regional stratigraphy of Eastern (Ponto-Caspian) Paratethys, much of it in sources not freely available in the west, is reviewed. Particular emphasis is placed on the South Caspian. Where possible, regional datums are calibrated against global standards. An attempt is made to place the regional stratigraphy in a (global) sequence stratigraphic framework for the first time. Palaeogeographic reconstructions are given for selected time-slices.

INTRODUCTION

The Tethyan Ocean began to close in the Eocene as a result of plate collisions along the southern margin of the Eurasian Supercontinent that ultimately gave rise to the formation of the mountain chain extending from the Alps in the west to the Himalayas in the east. The initial response to these plate collisions was the formation of a suite of east–west trending sedimentary basins extending from Austro-Hungary in the west to Central Asia in the east, collectively constituting the intracontinental Paratethyan Sea (Fig. 1). Subsequent tectonic uplift (enhanced by eustatic shallowing) through the Mio-Pliocene led to widespread marginal- to non- marine sedimentation. Ultimate severance of connections to the world's oceans led to the evolution of largely endemic faunas and floras (in particular in Eastern Paratethys, which was more isolated than Central Paratethys). This renders stratigraphic correlation between established Mediterranean and Paratethyan stages extremely difficult. The problem is locally compounded by confusion between chronostratigraphic and lithostratigraphic nomenclature.

In this paper we review all available data, much of it in sources not freely available in the west, on the regional stratigraphy of Eastern Paratethys (Fig. 1). We place particular emphasis on the South Caspian, an area in which the western oil industry is showing a growing interest, and one with which we, through our industrial work and our academic contacts in the Former Soviet Union, are particularly familiar.

We give an indication of the palaeontology of each regional stage. For the sake of brevity and because of their stratigraphic utility, we concentrate on various groups of microfossils, though we acknowledge that macrofossils, especially molluscs, also have stratigraphic value (see, for instance, Ali-Zade (1954), Azizbekov (1972), Ali-Zade *et al.* (1986), (Azerbaijan); Lupov *et al.* (1972) (Turkmenia); Andreescu (1981) (Dacic Basin); and Ozsayar (1985) and Taner (1985) (Turkey)). A forthcoming paper (Simmons *et al.* in press) will document in detail the micropalaeontological (including nannopalaeontological and palynological) and macropalaeontological zonation of the Neogene to Pleistogene sediments of Azerbaijan.

We attempt to place the regional stratigraphy in a global framework by calibrating biostratigraphic and magnetostratigraphic datums against Central Paratethyan and Mediterranean standards, and by suggesting possible calibrations between regional sequence boundaries and flooding surfaces, and the global sequence stratigraphic framework and eustatic sea-level curve of Haq *et al.* (1988).

ABSOLUTE CHRONOSTRATIGRAPHY

Notwithstanding the efforts of such authors as Steininger & Papp (1979), Chumakov *et al.* (1984, 1988, 1992a–b) and Vass (1985), there is no established comprehensive absolute chronostratigraphic time-scale for Eastern Paratethys. Thus, in Eastern Paratethys, absolute chronostratigraphic dating is often only possible by calibration of regional stratigraphic datums against global standards. We have attempted to calibrate regional datums against the Haq *et al.* (1988) timescale, which is the most up-to-date timescale that conveniently integrates bio-, magneto- and sequence- stratigraphic data. The confidence with which this sort of calibration can be made varies considerably with stratigraphic interval (see below).

MICROPALAEONTOLOGICAL BIOSTRATIGRAPHY AND PALAEOENVIRONMENTAL INTERPRETATION

Biostratigraphy

Those groups of planktonic organisms traditionally used in the biostratigraphic zonation of the Cenozoic (planktonic foraminifera and calcareous nannoplankton) are restricted in their development in Paratethys because of the isolated

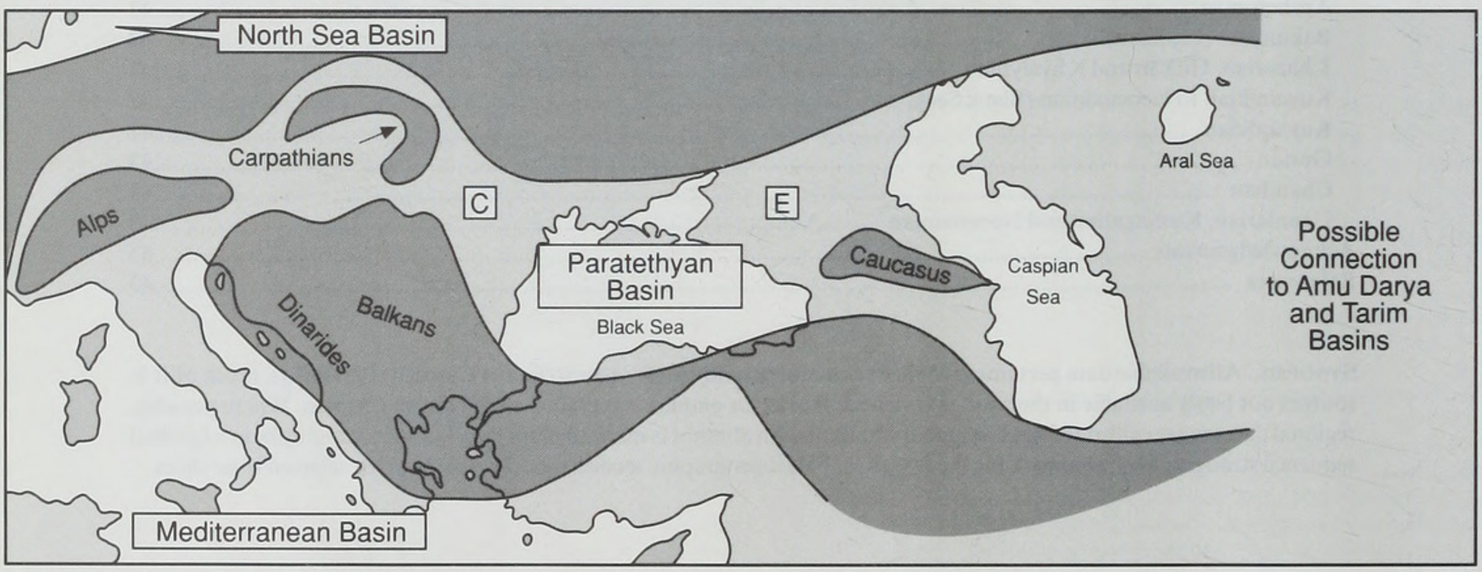

Fig. 1 Geological sketch map of the Paratethyan Basin in the Oligocene. Modified after Steininger & Papp (1979). C = Central Paratethys; E = Eastern Paratethys. Eastern Paratethys can be considered as including the Pontian (Black Sea) Basin and the Caspian Basin. Throughout most of the Miocene, the eastern limit of the Paratethyan Basin was probably the Caspian Basin, but in the Late Pliocene at least it was probably further east once more.

geological evolution of the region. Only locally or periodically (as in the Maykopian, Maeotian and Kuyalnikian/Akchagylian (see section below on sequence stratigraphy)) are they sufficiently well developed to enable ties to global biostratigraphic zonation schemes (Blow (1969) for planktonic foraminifera; Martini (1971) for calcareous nannoplankton).

Biostratigraphic zonation in Eastern Paratethys relies largely on facies-dependent benthonic foraminifera and, especially in the marginal- to non- marine environments of the Mio-Pliocene, benthonic ostracods and terrestrially-derived pollen and spores (see section below on sequence stratigraphy). Important ostracod references include those of Livental (1929), Sveier (1949), Agalarova (1956, 1967), Suzin (1956), Agalarova *et al.* (1961), Mandelstam *et al.* (1962), Faridi (1964), Imnadze (1964, 1974), Sheydayeva-Kuliyeva (1966), Rozyeva (1971), Gramann (1971), Karmishina (1975), Vekua (1975), Krstic (1976), Olteanu (1978), Imnadze & Karmishina (1980), de Deckker (1981), Jiricek (1984), Mamedova (1984, 1985, 1988), Dzhanelidze *et al.* (1985), Aliyulla *et al.* (1985) and Yassini (1986). Important pollen and spore and associated palynomorph references include those of Ramishvili (1969), Dzhabarova (1973, 1978, 1980), Grichuk (1973, 1984), Wall & Dale (1973), Ananova (1974), Shikmus *et al.* (1977), Koreneva & Kartashova (1978), Traverse (1978), Shchekina (1979), Abramova (1982, 1985), Yakhimovich *et al.* (1983), Grichuk *et al.* (1984), Khotinskiy (1984), Mamedov & Rabotina (1984a–b), Shatilova (1984), Ananova *et al.* (1985), Ivanova (1985), Sirenko & Turlo (1986), Bludorova *et al.* (1987), Naidina (1988, 1990a–b,

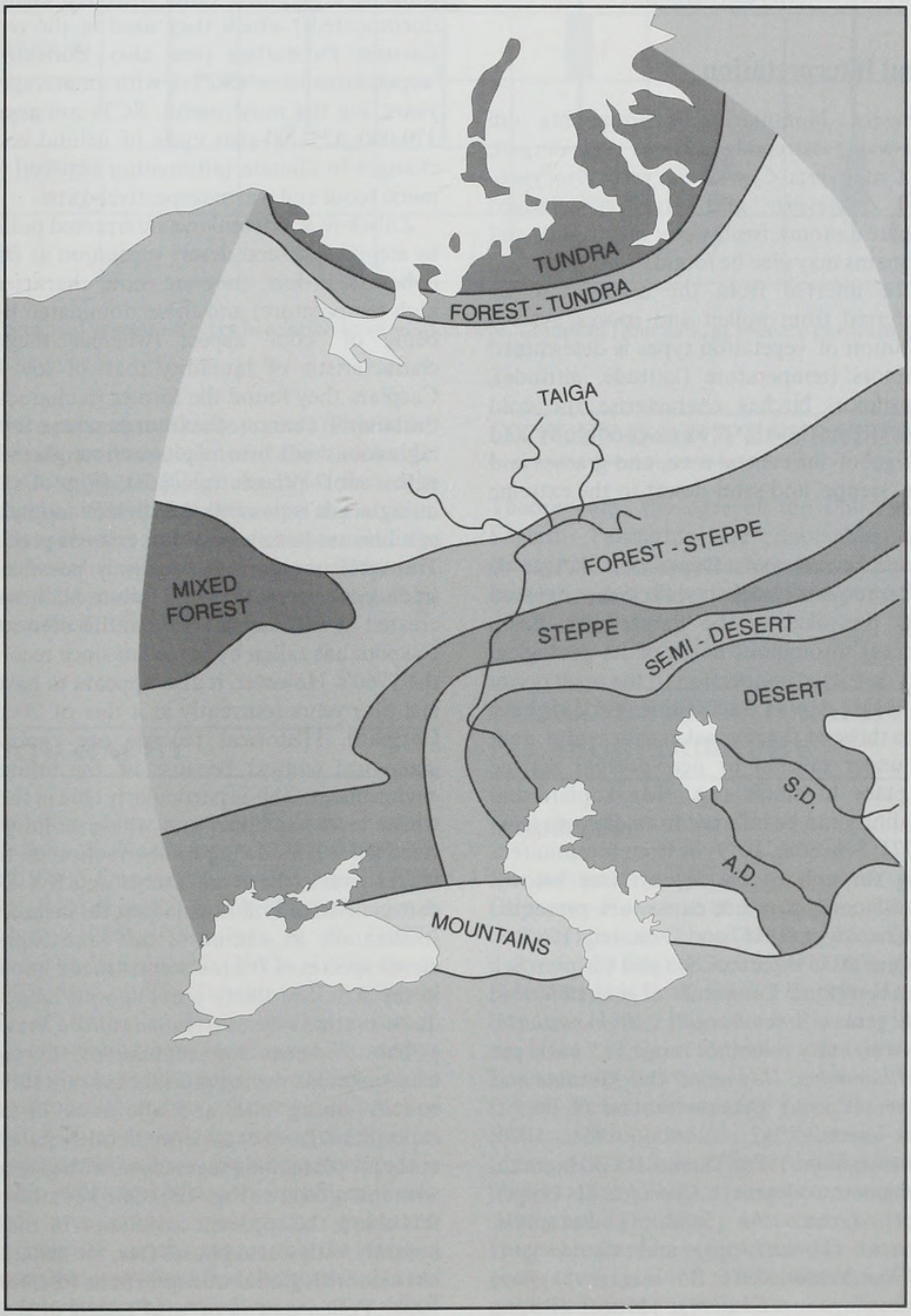

Fig. 2 Vegetation belts in the former Soviet Union. After Knystautas (1987). A.D. = Amu Darya; S.D. = Syr Darya.

1991a–c) and Malaeva & Kulikov (1991).

Other locally stratigraphically useful fossil groups include otoliths (Brzobohaty, 1983), Problematica (*Bolboforma* (Szczechura, 1985; Spiegler & Rögl, 1992)), siliceous microfossils (diatoms (Shishova, 1955; Ushakova & Ushko, 1971; Gasanova, 1965; Rasulov, 1986), radiolarians (Slama, 1983), silicoflagellates (Dumitrica, 1985) and sponge spicules (Riha, 1983)), and, in non-marine environments, vertebrate remains (*Camelopardis, Felis, Gazella, Hipparion, Hyaena, Mastodon, Mesopithecus, Rhinoceros,* etc.) (Kretzoi, 1985; Steininger, Rabeder & Rögl, 1985; Bernor *et al.*, 1987, 1993; Lindsay *et al.*, 1989; Rögl *et al.*, 1993) and charophytes (Rögl *et al.*, 1993).

Ali-Zade *et al.* (1994a, 1994b, 1995, in press), Reynolds *et al.* (in press) and Simmons *et al.* (in press) give further details of the Neogene biostratigraphy of Eastern Azerbaijan.

Palaeoenvironmental Interpretation

Non-Marine Environments. Non-marine environments are characterised by fresh-water ostracods such as *Aglaiocypris, Candona, Candonella, Cyclocypris, Cypria, Eucypris, Ilyocypris, Pseudostenocypria* and *Zonocypris*, and terrestrially-derived pollen and spores. Pennate diatoms, fresh-water gastropods and terrestrial vertebrate remains may also be found.

Palaeoclimate can be inferred from the distribution of vegetation types as inferred from pollen and spores. At the present-day, the distribution of vegetation types is determined chiefly by climatic factors (temperature (latitude, altitude), aridity). Thus, for instance, birches characterise the cold 'forest-tundra' of the extreme north, diverse coniferous and deciduous types the 'taiga' of the central area, and grasses and shrubs the arid treeless 'steppe' and semi-desert to the extreme south (Figs 2–3).

Quasi-Marine and Marine Environments. Deposition in oligo- to meso- haline (hereafter 'quasi-marine' (brackish, reduced salinity)) environments prevailed in the Paratethyan Basin (especially in the Caspian) throughout much of its geological evolution because of its restricted connection to the open ocean (see above). However, water depths and sedimentary regimes may have been similar to those of the normal marine realm, and, moreover, deposition under normal or near-normal marine conditions did take place at times (e.g., Maykopian and Akchagylian). Palaeosalinity can be inferred from diatoms (e.g., Ushakova & Ushko, 1971; Schrader, 1979) or from foraminifera and ostracods ranging through to the Recent (see below). Palaeosalinity and/or palaeotemperature curves are presented by Semenenko (1979), Chepalyga (1985) and Demarcq (1985).

Quasi-marine environments in the Black Sea and Caspian Sea are characterised by the benthonic foraminiferal genus *Florilus*, and some species of the genera *Ammobaculites, Ammoscalaria, Ammonia* and *Elphidium* (salinity tolerance range 1–5 parts per thousand (ppt)), and *Miliammina, Haynesina* and *Rosalina* and some species of *Nonion s.l.* and *Quinqueloculina* (1–26ppt) (Macarovici & Cehan-Ionesi, 1962; Tufescu, 1968, 1973; Murray, 1973, 1991; Gheorghian, 1974; Yassini & Ghahreman, 1977; Yanko, 1990b), the ostracod genera *Cyprideis* (2–14ppt), *Maetocythere* (4–14ppt), *Loxoconcha* (5–14ppt), *Bakunella, Caspiolla* and *Cytherissa* (11–13/14ppt) and *Graviacypris* (12–13ppt) (Gofman, 1966; Yassini, 1986; Boomer, 1993a), and the calcareous nannofossil genus *Emiliania* (11ppt) (Bukry, 1974).

Normal or near-normal marine environments are characterised by the benthonic foraminiferal genera *Discorbis, Textularia, Bolivina, Bulimina, Brizalina, Cibicides, Gavelinopsis* and *Trifarina* and some species of the genera *Ammonia, Nonion s.l.* and *Quinqueloculina* (salinity tolerance range 11–26ppt) (Macarovici & Cehan-Ionesi, 1962; Tufescu, 1968, 1973; Murray, 1973, 1991; Yassini & Ghahreman, 1977; Yanko, 1990b).

CLIMATOSTRATIGRAPHY

Zubakov & Borzenkova (1990) defined a series of climatostratigraphic units called 'climathems' (some conceptual, some stratotypified (and with representative pollen spectra documented)) which they used in the regional correlation of Eastern Paratethys (see also Zubakov, 1993). Of these, 'superclimathems' (SCTs), with an average duration of 200,000 years, are the most useful. SCTs are correlated with half the 370,000–425,000-year cycle of orbital eccentricity, and reflect changes in climate (alternating between 'cryo-' and 'thermo-' meric (cool and warm respectively)).

Zubakov & Borzenkova interpreted pollen spectra dominated by steppe and semi-desert vegetation as being of 'warm' aspect (whereas, in fact, they are more characteristic of aridity than high temperature) and those dominated by forest vegetation as being of 'cool' aspect (whereas they are in fact more characteristic of humidity than of low temperature). In the Caspian, they found the former to characterise regressions and the latter to characterise transgressions, and therefore correlated regressions with 'warm' phases (interglacials) and transgressions with 'cool' phases (glacials) (Fig. 4A). Regression during interglacials is possible if sediment supply and subsidence are in equilibrium but evaporation exceeds precipitation and run-off. Transgression during glacials is possible if sediment supply (reduced by rivers freezing) fails to fill the accommodation space created by subsidence. Note in this context that the level of the Caspian has fallen by some 5m since records were first taken in the 1760's. However, it also appears to have been rising over the last fifty years (currently at a rate of 20cms/year in the South Caspian). Historical records are probably unreliable in a geological context because of the influence of man on the environment. This is particularly true in the case of the Aral Sea, whose level has fallen and whose salinity has risen drastically since the 1960's owing to abstraction of the headwaters of the feeder rivers (the Amu Darya and Syr Darya) to irrigate the cotton fields of Uzbekistan (see, for instance, Boomer, 1993a–b). Incidentally, as a result of this catastrophic ecological change, eleven species of fresh-water ostracod known to have been living in the Aral Sea thirty years ago no longer live there. Only the quasi-marine species *Cyprideis torosa* lives there today.

The evidence for regressions during interglacials and transgressions during glacials appears somewhat equivocal. An equally strong case, and one more in keeping with *a priori* expectation from experience in other parts of the world, can be made for correlating regressions with glacials and transgressions with interglacials (Fig. 4B). One key observation in support of this case is the apparent correlation of the major transgressions not only with warm phases (see, for instance, Skalbdyna, 1985), but also with global transgressions (see, for instance, Haq *et al.*, 1988). Pollen spectra of 'arid' aspect in glacial sediments and of 'humid' aspect in interglacial sediments are explicable in terms of, respectively, contractions and expansions of the forest belt

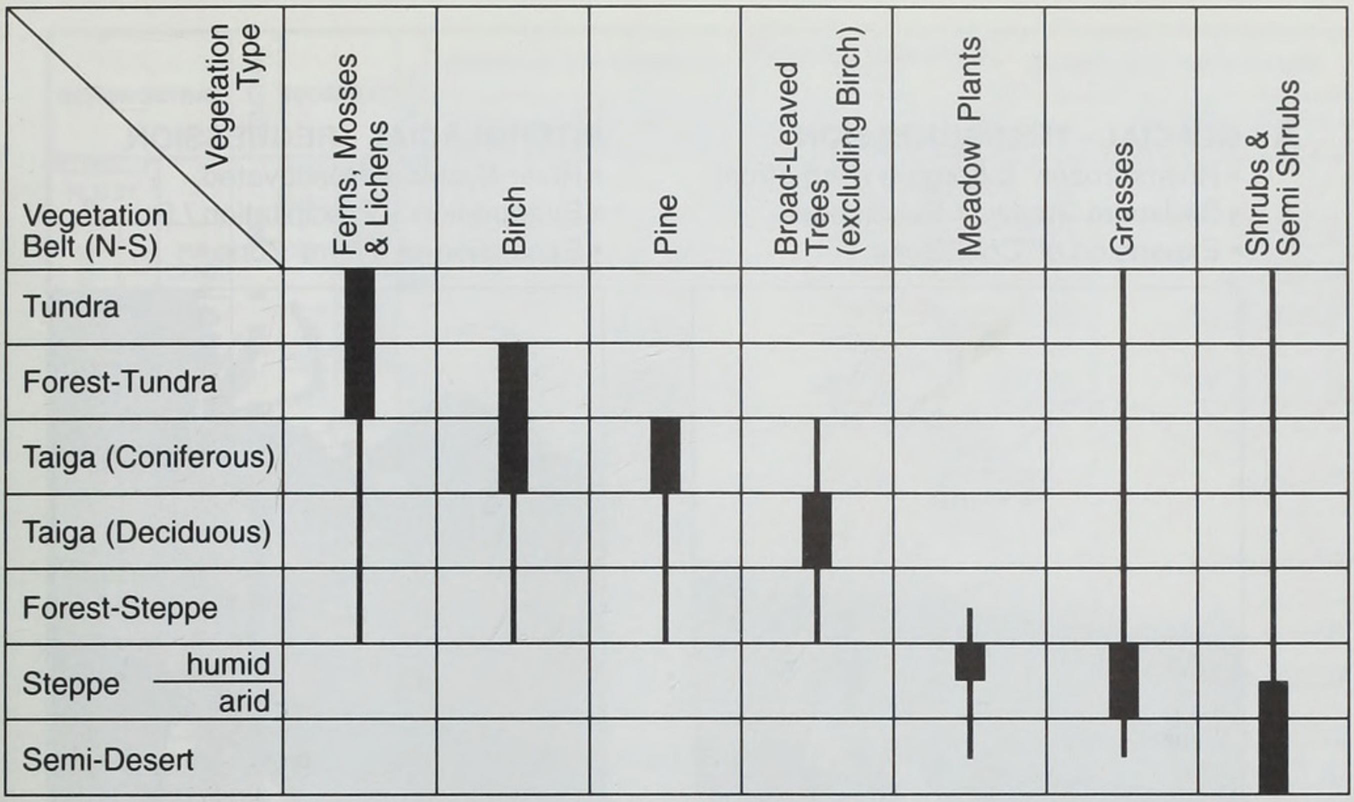

Fig. 3 Distribution of principal vegetation types in relation to vegetation belts. Compiled from various sources. Bar width provides a measure of abundance.

(the former in response to permafrost development). This is also indicated by palaeoclimatic reconstructions for the Late Valdai Glacial and Mikulino Interglacial (Grichuk, 1984; Savina & Khotinskiy, 1984; Velichko, 1984b). An alternative explanation envisages a time lag between the onset of glaciation and the response of vegetation (belts being displaced by up to 2000km.). Similar disequilibrium phenomena have been described from interstadial complexes in the United Kingdom.

MAGNETOSTRATIGRAPHY

Much magnetostratigraphic data is available from Eastern Paratethys (e.g., Zubakov & Kochegura (1971), Trubikhin (1977), Semenenko (1979), Semenenko & Pevzner (1979), Grishanov *et al.* (1983), Rögl & Steininger (1984), Steininger & Rögl (1984), Chepalyga (1985), Chepalyga *et al.* (1985), Iossofova (1985), Pevzner & Vangengeim (1985a, 1993), Senes (1985), Skalbdyna (1985), Vass (1985), Zubakov & Borzenkova (1990) and Trubikhin *et al.* (1991a–b)). Theoretically, this sort of data ought to enable a correlation between Eastern Paratethys and the rest of the world (which, as noted above, is difficult to do using the available biostratigraphic data). However, in practice the process is complicated by apparently inconsistent definition and usage of magnetostratigraphic units (polarity epochs). It is beyond the scope of this paper to address this problem in any more detail (instead, we simply quote the published magnetostratigraphic (polarity epoch) ranges for the various regional stages). It is nonetheless evident that the potential exists for a refined magnetostratigraphic subdivision of critical intervals using short-lived polarity reversal 'episodes' within the longer-term epochs.

OXYGEN ISOTOPE STRATIGRAPHY

Theoretically, the ages of the Plio-Pleistogene sediments of Eastern Paratethys are resolvable using oxygen isotope stratigraphic techniques. However, in practice, what data there is exists in widely disseminated form and is not particularly useful.

SEQUENCE STRATIGRAPHY AND PALAEOGEOGRAPHY

Introduction

No published sequence stratigraphic schemes exist for the Oligocene-Holocene of Paratethys, although relative sea-level changes and associated aspects of sequence stratigraphy are discussed by Rögl & Steininger (1983), Chepalyga (1985, 1991), Demarcq (1985), Krhovsky (1985), Nevesskaya *et al.* (1985), Pogacsas (1985), Pogacsas & Revesz (1985), Skalbdyna (1985), Andalibi (1991), Zubakov & Borzenkova (1990) and Klopovotskaya (1991).

This section attempts to place the regional stratigraphy of Eastern Paratethys in a (global) sequence stratigraphic framework. It is written in the form of a geological history. Stratigraphic (bio-, climato-, magneto- and sequence-stratigraphic) data are summarised on Figs 5–6. Palaeogeographic reconstructions for selected time-slices are given on Figs 7–12. These are based in part on previously published maps (Podobina *et al.*, 1956; Muratov, 1960; Sheydayeva-Kuliyeva, 1966; Ushakova & Ushko, 1971; Senes, 1973; Azizbekova, 1974; Senes & Marinescu, 1974; Luttig &

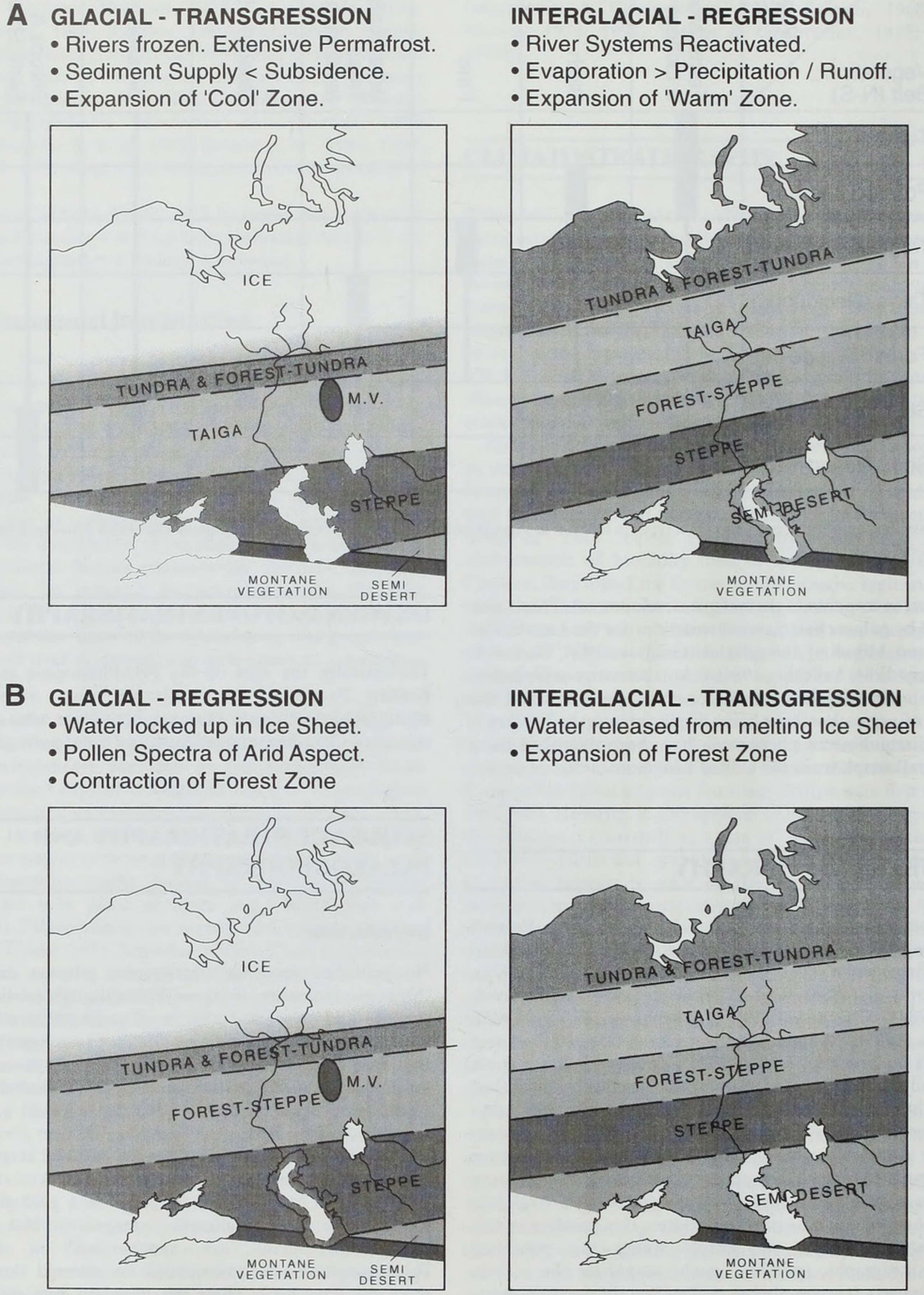

Fig. 4 Response to glaciation – alternative models for the Caspian. A: glacial transgression/interglacial regression. B: glacial regression/interglacial transgression. B better follows the palaeoclimatic reconstruction data given by Grichuk (1984) (see text).

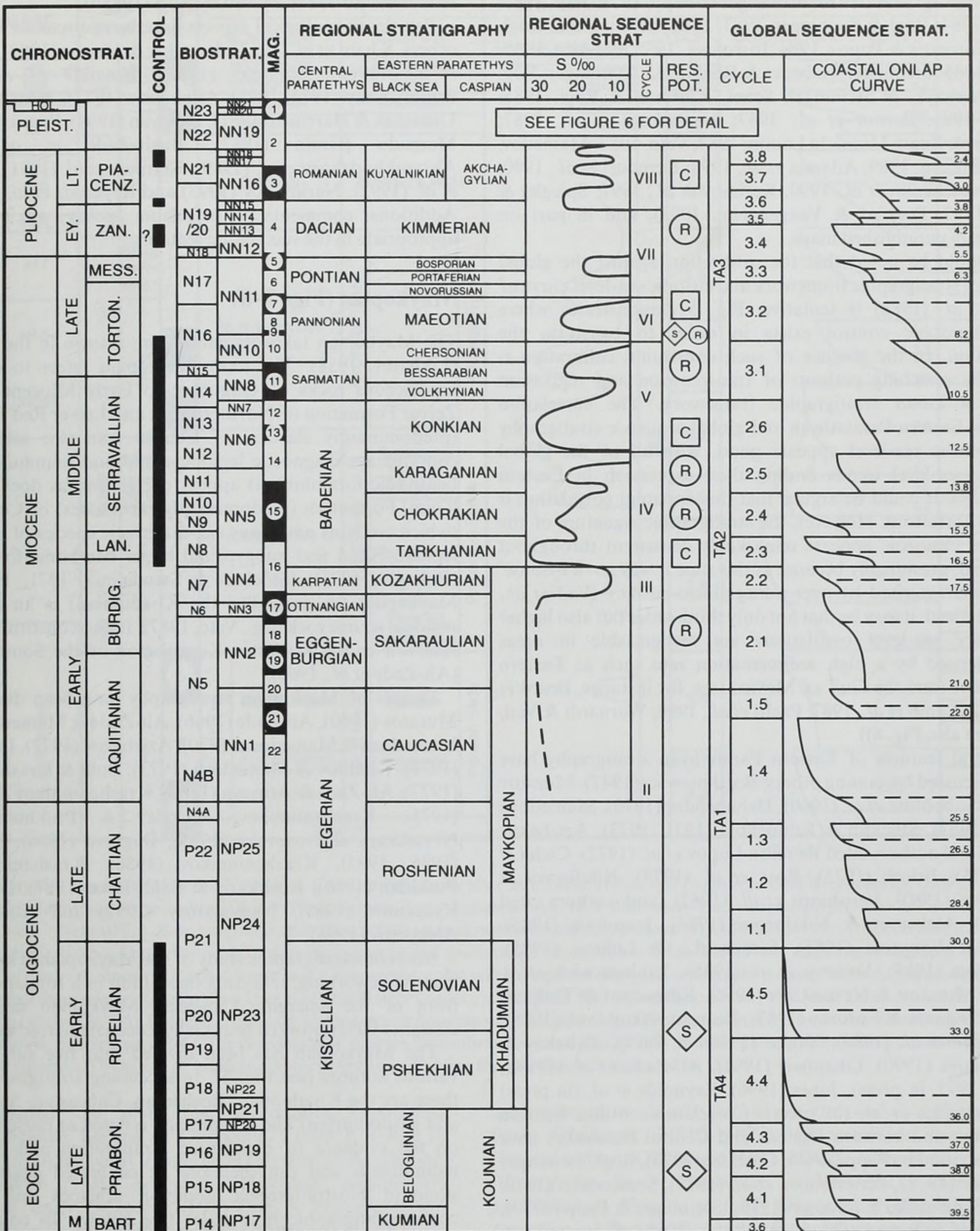

Fig. 5 Stratigraphic summary (Eocene-Holocene). Chronostratigraphy, magnetostratigraphy, global sequence stratigraphy and calibration after Haq *et al.* (1988) (see also chronostratigraphic schemes of Chumakov *et al.*, 1984, 1988, 1992a–b and others). Sequence boundary ages in Ma. Biostratigraphy after Blow (1969) (planktonic foraminifera) (prefixed P and N) and Martini (1971) (calcareous nanoplankton) (prefixed NP and NN). Regional stratigraphy from this paper. Regional sequence stratigraphy modified after Chepalyga (1985). Cycles are regressive (mega) sequences. II–III are equivalent to the 'Eoparatethyan', IV to the 'Mesoparatethyan' and V–VI to the 'Neoparatethyan' of Nevesskaya *et al.* (1985). Curve shows extent of open marine connection (function of sea-level) as inferred from salinity data from palaeontological analyses (S‰ = salinity parts per thousand). Res. pot. = Resource potential (S = source, R = reservoir, C = caprock). The correlation of Eastern Paratethyan sequence stratigraphy with the global coastal onlap curve of Haq *et al.* (1988) is tentative. Where biostratigraphic control constrains the correlation this is indicated.

Steffens, 1976; Steininger, Rögl & Martini, 1976; Hsu, *in* Ross *et al.*, 1978; Rögl *et al.*, 1978; Steininger & Papp, 1979; Hsu, 1983; Baldi, 1984; Rögl & Steininger, 1983, 1984; Steininger & Rögl, 1984; Voronina & Popov, 1984; Iossofova, 1985; Popescu, 1985; Rusu, 1985; Steininger, Rabeder & Rögl, 1985; Steininger, Rögl & Nevesskaya, *in* Steininger, Senes, Kleeman & Rögl, 1985; Voicu, 1985; Bernor *et al.*, 1987; Nevesskaya *et al.*, 1987; Panakhi & Buare Mamadu Lamin, 1987; Veto, 1987; Mamedov, 1989; Olteanu, 1989; Adamia *et al.*, 1990; Dercourt *et al.*, 1990; Tchoumatchenko *et al.*, 1990; Kerimov *et al.*, 1991; Spiegler & Rögl, 1992; Pevzner & Vangengeim, 1993), and in part on previously unpublished maps.

It should be noted that the calibration against the global sequence stratigraphic framework and eustatic sea-level curve of Haq *et al.* (1988) is tentative. Fig. 5 demonstrates where biostratigraphic control exists in order to constrain the calibration. In the absence of such constraint, calibration is made by matching patterns of transgression and regression within a looser stratigraphic framework. The correlation between Eastern Paratethyan and global sequence stratigraphy and eustatic sea-level appears good, with all of the global eustatic sea-level trends finding their expression in Eastern Paratethys. It could be argued that this apparent correlation is entirely fortuitous. However, the stratigraphic signature of the mid-late Cenozoic appears remarkably consistent throughout the world, presumably because at this time it was an 'ice-house' world characterised by over-riding glacio-eustacy (Vail *et al.*, 1991). Indeed, it may be that not only third-order but also higher frequency sea-level oscillations are recognisable in areas characterised by a high sedimentation rate such as Eastern Paratethys (and the Gulf of Mexico (see, for instance, Beard *et al.*, 1982; Lamb *et al.*, 1987; Pacht *et al.*, 1990; Wornardt & Vail, 1990; see also Fig. 6)).

General features of Eastern Paratethyan stratigraphy have been discussed by, among others, Bogdanowicz (1947), Muratov (1960), Subbotina *et al.* (1960), Dzhanelidze (1970), Mamedova (1971, 1987), Stöcklin & Setudehnia (1971, 1972), Azizbekov (1972) (and authors cited therein), Lupov *et al.* (1972), Cicha *et al.* (1975), Jiricek (1975), Ross *et al.* (1978), Nikiforova & Dodonov (1980), Verisharin *et al.* (1982) (and authors cited therein), Alekseyev & Nikiforova (1984), Iossofova (1985), Popov & Voronina (1985), Semenenko & Lulieva (1985), Skalbdyna (1985), Volkova *et al.* (1985), Yakhemovich *et al.* (1985), Muratov & Nevesskaya (1986), Kereudren & Thibault (1987), Nigarov & Fedorov (1987), Benyamovskoy *et al.* (1988), Steininger *et al.* (1989), Yanko (1990a–b, 1991), Zubakov & Borzenkova (1990), Ghanbari (1991), Ali-Zade *et al.* (1994a, 1994b, 1995, in press), Jones (1996), Reynolds *et al.* (in press) and Simmons *et al.* (in press). Correlations within Eastern Paratethys and between Eastern and Central Paratethys have been discussed by Papp (1969), Chelidze (1973), Rögl, Steininger & Muller (1978), Paramonova *et al.* (1979), Semenenko (1979, 1984), Semenenko & Pevzner (1979), Steininger & Papp (1979), Steininger & Rögl (1979, 1984), Baldi (1980), Semenenko & Lulieva (1982), Rögl & Steininger (1983, 1984), Nevesskaya *et al.* (1984, 1985, 1987), Velichko (1984a), Yakhimovich, Bludorova, Zhidovinov *et al.* (1984), Chepalyga *et al.* (1985), Nevesskaya & Nosovsky (1985), Nosovsky (1985), Pevzner & Vangengeim (1985), Rögl (1985a), Senes (1985a–b), Senes & Steininger, in Steininger *et al.* (1985), Yakhimovich, Bludorova, Chiguryaeva *et al.* (1985), Zosimovich *et al.* (1985), Yassini (1986), Mekhtiev & Pashaly (1987), Muzylev & Golovina (1987), Steininger *et al.*, in Royden & Horvath (1987), Olteanu (1989), Rögl *et al.* (1991), Fedorov (1994), Markova & Mikhailesku (1994) and Jones (1996). A comprehensive bibliography of general stratigraphic references (to 1984) is given by Rögl (1985b).

Petroleum geological aspects have been discussed by, among others, Khain *et al.* (1937), Ismailov & Idrisov (1963), Ali-Zade *et al.* (1966), Shilinski (1967), Ismailov *et al.* (1972), Buryakovsky (1974, 1993), Alikhanov (1977), Nikishin (1981), Ulmishek & Harrison (1981), Babayan (1984), Panakhi & Buare Mamadu Lamin (1987), Bagir-Zade *et al.* (1988), Akramkhodzhaev *et al.* (1989), Kerimov *et al.* (1991), Kleschev *et al.* (1992), Narimanov (1993) and Reynolds *et al.* (in press). Additional comments on petroleum geology are inserted as appropriate in the succeeding sections.

Maykopian (Figs 7–8)

The Maykopian takes its name from a town in the Caucasus (Likharev, 1958). The term Maykopian refers to essentially argillaceous rocks of Oligocene to Early Miocene age. The Zeivar Formation of Northern Iran and Lower Red Formation (predominantly clastics) of Central Iran (the latter locally contains age-diagnostic lepidocyclinid and nummulitid larger benthonic foraminifera) appear correlative, as does the Qom [Qum] Formation (predominantly carbonates) of Central Iran (which contains numerous age-diagnostic species of alveolinid, lepidocyclinid and miogypsinid larger benthonic foraminifera (Rahaghi, 1973)) (Stöcklin & Setudehnia, 1971, 1972). The Maykopian (in particular the Khadumian) is an important regional source rock (e.g., Veto, 1987). It also constitutes a minor reservoir in the Kobustan-Kura region of the South Caspian (Ali-Zade *et al.*, 1966).

Details of Maykopian stratigraphy have been discussed by Muratov (1960), Ali-Zade (1966), Ali-Zade & Mamedov (1970), Mamedova & Mamedova (1970), Azizbekov (1972), Lupov *et al.* (1972), Khalilov & Mamedova (1973), Bolli & Krasheninnikov (1977), Ali-Zade & Atayeva (1982), Krasheninnikov & Muzylev (1975), Krasheninnikov, Muzylev & Ptukhian (1985), Nevesskaya & Nosovsky (1985), Bugrova (1986), Koshkarly (1986, 1993), Krasheninnikov (1986), Krasheninnikov & Ptukhian (1986), Koshkarly & Baldi-Beke (1987), Gasanov & Kyazamov (1988), Nagymarosy (1992) and Koshkarly & Alekperov (1993).

Microbiostratigraphic study of the Maykopian is hindered by massive reworking, reflecting deposition in a foreland basin in front of the emerging Caucasus. Maykopian samples can contain >90% reworked (especially Eocene) microfossils.

The Maykopian has been divided into five sub-stages by various authors (see Fig. 5). In ascending stratigraphic order, these are the Khadumian, Roshenian, Caucasian, Sakaraulian and Kozakhurian. The Khadumian is dated as Early Oligocene on the evidence of planktonic foraminifera and calcareous nannofossils and can therefore be calibrated against global standard biostratigraphic zonation schemes and absolute chronostratigraphic time-scales (see below). In contrast, the Roshenian is dated as Late Oligocene and the Caucasian to Kozakhurian as Early Miocene essentially only on the evidence of benthonic foraminifera (see, for instance, Nevesskaya & Nosovsky, 1985).

The youngest sub-stages of the Maykopian appear to be absent in the Dacian Basin in the Western Black Sea region (Steininger *et al.*, in Royden & Horvath, 1987).

Micropalaeontology and Nannopalaeontology. The Khadumian has been dated as Early Oligocene on both planktonic foraminiferal and calcareous nannoplankton evidence. Ali-Zade

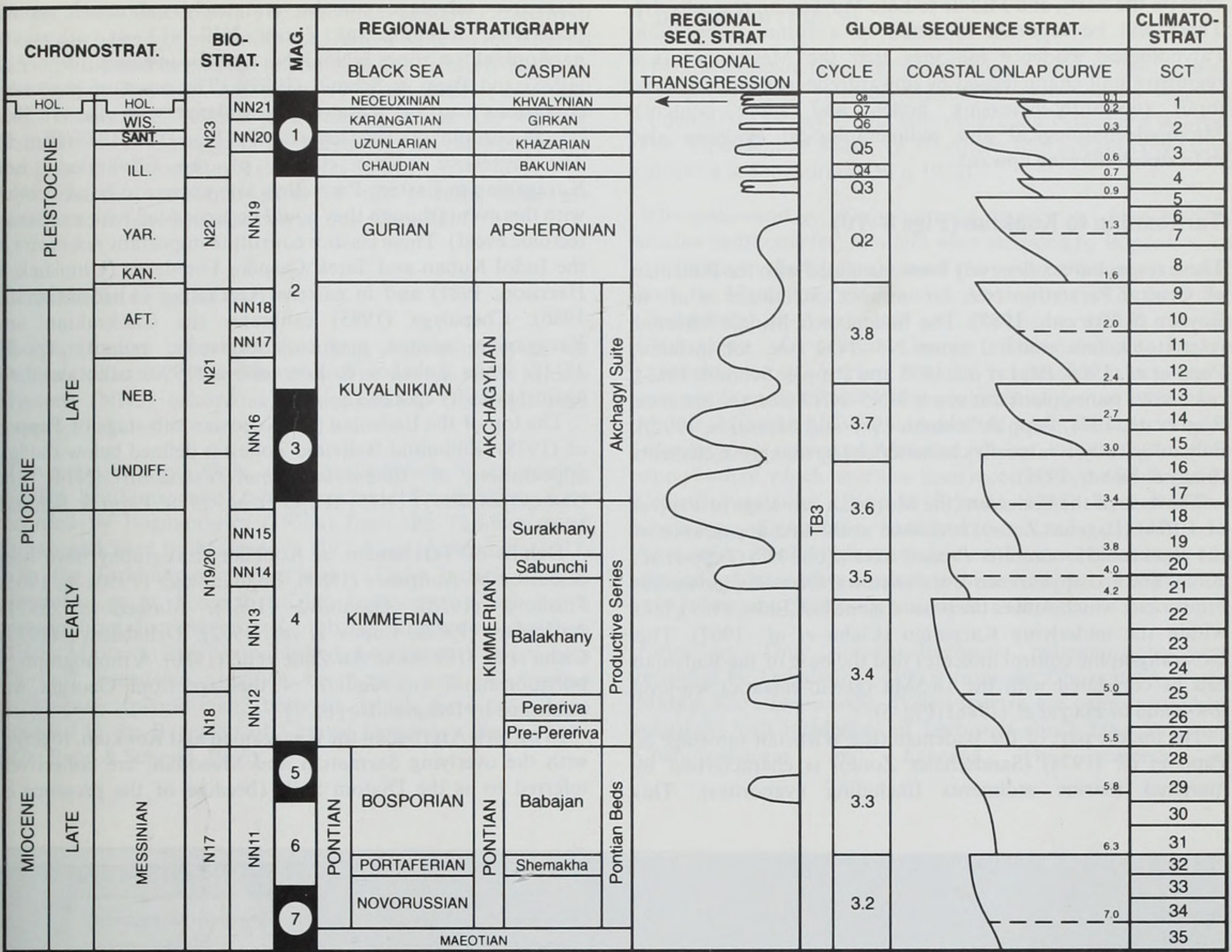

Fig. 6 Stratigraphic summary (Miocene-Holocene). Chronostratigraphy after Beard *et al.* (1982) and Lamb *et al.* (1987) (conceptual Gulf of Mexico deep-water stage nomenclature) (Wis. = Wisconsinian; San. = Sangamonian; Ill. = Illinoisian; Yar. = Yarmouthian; Kan. = Kansan; Aft. = Aftonian; Neb. = Nebraskan). Biostratigraphy after Blow (1969) (planktonic foraminifera) (prefixed N) and Martini (1971) (calcareous nannoplankton) (prefixed NN). Magnetostratigraphic polarity epochs and absolute age values are after Haq *et al.* (1988). Regional stratigraphy from this paper (upper case = chronostratigraphic, lower case = lithostratigraphic units). Regional sequence stratigraphy (transgressions) after Skalbdyna (1985). Global sequence stratigraphy after Haq *et al.* (1988) (third-order cycles TB3.2–TB3.8), and Beard *et al.* (1982) and Lamb *et al.* (1987) (fourth-order cycles Q2–Q8). Sequence boundary and maximum flooding surface ages in Ma. Climatostratigraphy (superclimathems or SCTs) after Zubakov & Borzenkova (1990). The correlation of Eastern Paratethyan sequence stratigraphy with the global coastal onlap curve of Haq *et al.* (1988) is tentative. The extent of biostratigraphic control constraining the correlation is indicated on Fig. 5.

(1966) recorded the planktonic foraminifer *Globigerina officinalis* (Middle Eocene to Oligocene, Zones P14–P22 of Blow, 1969) from the basal '*Planorbella* Horizon' in Azerbaijan. Krasheninnikov (1986) recorded planktonic foraminifera indicative of Early Oligocene (P18) from a stratigraphically similar position (immediately below the 'Ostracod-Horizon') in the Kuban-Kuma Interfluve (North Caucasus). Krasheninnikov *et al.* (1985) recorded *Globigerina tapuriensis* (Oligocene, P18–P20) associated with the larger benthonic foraminifer *Nummulites intermedius* (Early Oligocene) from the Khadumian of Armenia. Later, Krasheninnikov & Ptukhian (1986) recorded *Globigerina sellii* (Oligocene, P19/20 to 'early' P22) associated with *Nummulites intermedius* (also Oligocene) and the calcareous nannofossil *Helicosphaera reticulata* (Eocene to Early Oligocene, Zones NP17–NP22 of Martini, 1971) from the Khadumian of Armenia. Koshkarly (1986) recorded the calcareous nannofossils *Reticulofenestra umbilica* (Eocene to Early Oligocene, NP16–NP22), *Chiasmolithus oamaruensis* (Eocene to Early Oligocene, NP18–NP22), *Isthmolithus recurvus* (Eocene to Early Oligocene, NP19–NP22), *Sphenolithus pseudoradians* (Eocene to Early Oligocene, NP20–NP23) and *Ericsonia subdisticha* (Eocene to Early Oligocene, NP20–NP21) from the Khadumian of Azerbaijan. Later, Koshkarly & Baldi-Beke (1987) recorded *R. umbilica, C. oamaruensis, I. recurvus* and *S. pseudoradians,* and Koshkarly & Alekperov (1993) *H. reticulata* and *E. subdisticha* from the Early Maykopian of Azerbaijan.

Palynology. Although only non-age-diagnostic palynomorphs were recorded from the Maykopian of the Middle Kura Depression by Dzhabarova (1973), recent observations suggest that some age-diagnostic dinocysts, and pollen and spores do exist (in the Early, and Middle to Late Maykopian respectively). These will be reported in detail in a future publication. Palynological evidence indicates that the Maykopian is a regressive unit characterised by upwardly-increasing terrestrial input (upwardly-increasing pollen and spore content). Micropalaeontological and sedimentological evidence also indicates shallowing upward.

Tarkhanian to Konkian (Figs 8–10)

These stages have collectively been correlated with the Badenian of Central Paratethys (see, for instance, Steininger *et al.*, in Royden & Horvath, 1987). The Badenian is Middle Miocene (planktonic foraminiferal zones N8–?N12 (see, for instance, Papp *et al.*, 1968, Rögl *et al.*, 1978 and Papp & Schmid, 1985); calcareous nannoplankton zones NN5–NN7 (see, for instance, Rögl *et al.*, 1978, Papp & Schmid, 1985 and Meszaros, 1992)). Palynologically, it is locally characterised by mangrove elements (Nagy & Kokay, 1991).

The base of the Badenian (the Moravian sub-stage of Papp *et al.* (1978) (Lagenid Zone)) is defined at the first appearance of the planktonic foraminifer *Praeorbulina* (Zone N8) (Papp *et al.*, 1968). The first appearance of the ancestral form *Globigerinoides bisphericus,* which defines the base of Zone N8 (Blow, 1969), falls within the underlying Karpatian (Cicha *et al.*, 1967). This biostratigraphic control indicates that the base of the Badenian can be correlated with the 16.5Ma (glacio-eustatic) sea-level low-stand of Haq *et al.* (1988) (Fig. 5).

The middle part of the Badenian (the Wielician sub-stage of Papp *et al.* (1978) (Sandschaler Zone)) is characterised by marginal marine sediments (including evaporites). This regressive sub-stage can be tentatively calibrated against planktonic foraminiferal Zones N10–N12 or calcareous nannoplankton zones NN5–NN6 (see, for instance, Rögl *et al.* (1978) and Papp & Schmid (1985)). The onset of regressive conditions can be tentatively correlated with the 15.5Ma (glacio-eustatic) sea-level low-stand of Haq *et al.* (1988) (Fig. 5). The regressive coarse clastics of the Chokrakian and Karaganian in Eastern Paratethys also appear to be associated with this event (though they could be associated with a separate tectonic event). These clastics constitute important reservoirs in the Indol Kuban and Terek Caspian Foredeeps (Ulmishek & Harrison, 1981) and in eastern Azerbaijan (Ali-Zade *et al.*, 1986). Chepalyga (1985) calibrates the Chokrakian and Karaganian against magnetostratigraphic polarity epochs 15–12, while Zubakov & Borzenkova (1990) calibrate them against polarity epochs 16–14.

The top of the Badenian (the Kosovian sub-stage of Papp *et al.* (1978) (Buliminid-Bolivinid Zone)) is defined below the last appearances of *Globorotalia mayeri/siakensis* (N14) and *Globigerina druryi* (N15) (Papp *et al.*, 1978; Papp & Schmid, 1985).

Details of Tarkhanian to Konkian stratigraphy have been discussed by Andrusov (1884), Bogdanowicz (1950a–b, 1965), Shishova (1955), Gasanova (1965), Mamedova (1971), Azizbekov (1972), Lupov *et al.* (1972), Dzhabarova (1973), Cicha *et al.* (1983) and Ali-Zade *et al.* (1986). A monograph of polymorphinid foraminifera of this age from Georgia was published by Dzharelidze (1977).

In eastern Azerbaijan the Karaganian and Konkian, together with the overlying Sarmatian and Maeotian, are collectively referred to as the Diatom Suite (because of the presence of

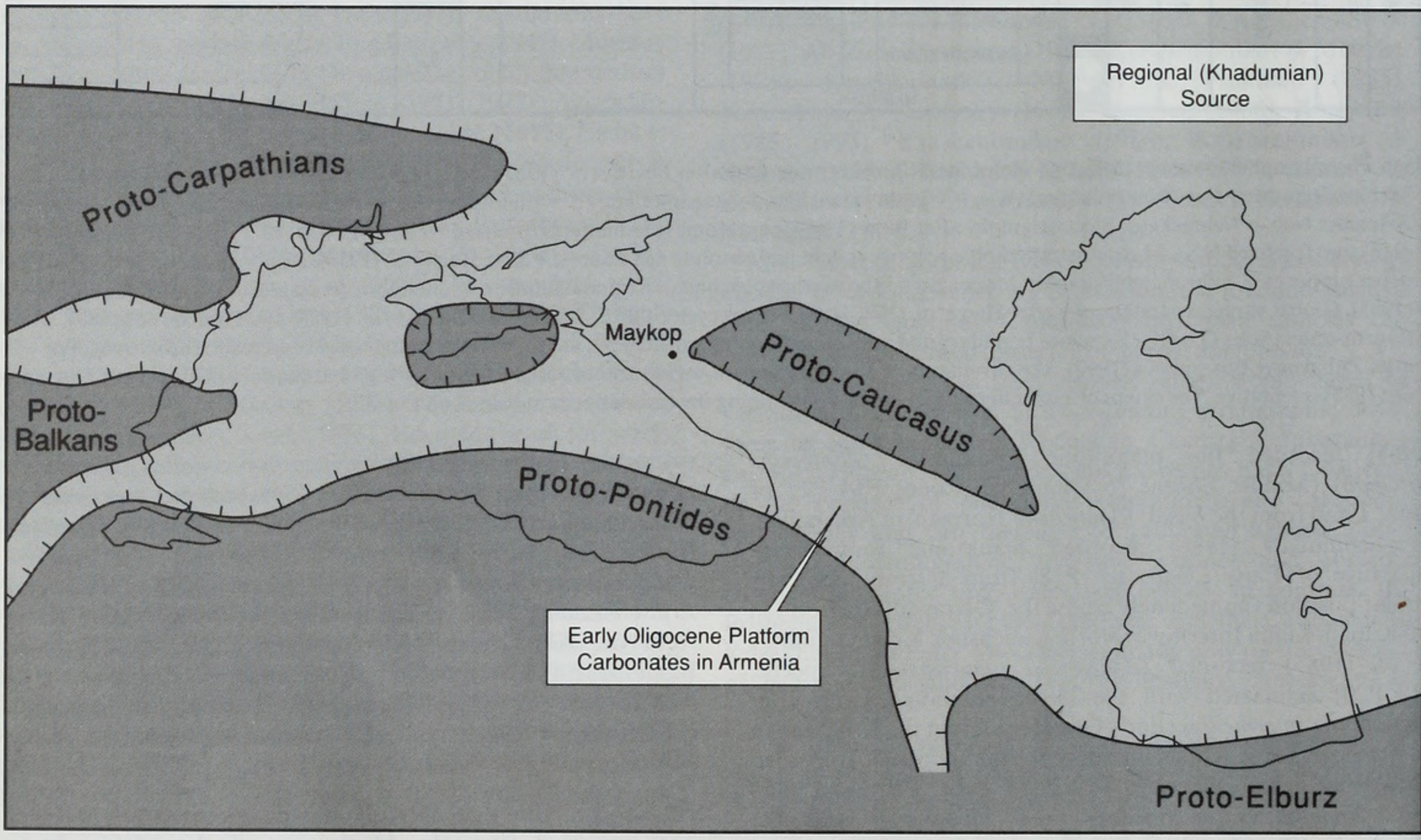

Fig. 7 Palaeogeographic reconstruction, Early Maykopian (Early Oligocene). Solid line indicates relatively well constrained, dashed line poorly constrained shoreline. Ticks on landward side. The location of the Maykopian stratotype is indicated.

diatomaceous limestones). The individual Eastern Paratethyan stages can be recognised within the Diatom Suite on the basis on fish otoliths and benthonic microfossils (particularly molluscs and foraminifera (e.g., Azizbekov, 1972; Ali-Zade *et al.*, 1986) and diatoms (E.Z. Ateava, pers. comm., 1994)). The work of Dzhabarova (1973) suggests that palynology may also be used to recognise the various stages (see notes below).

In eastern Azerbaijan parts of the Diatom Suite are considered to have hydrocarbon source potential.

Tarkhanian (Fig. 8)

The Tarkhanian takes its name from a promontory in the Crimea (Likharev, 1958). The stratotype section yields Middle Miocene (NN5) calcareous nannoplankton (F. Rögl, pers. comm., 1994).

Micropalaeontology. Only non-age-diagnostic quasi-marine, smaller benthonic and rare planktonic foraminifera were recorded by Bogdanowicz (1950a) from the Tarkhanian of Kuban and later by Mamedova (1971) and Azizbekov (1972) from the Tarkhanian of Azerbaijan. These include *Rotalia* [*Ammonia*] ex gr. *beccarii* (smaller benthonic), which has a cosmopolitan distribution and probably ranges no older than Middle Miocene (RWJ's unpublished observations), and *Nonion* [*Florilus*] *boueanum* (smaller benthonic) and *Globigerina tarchanensis* (planktonic), both of which have also been recorded in the Badenian of Central Paratethys (Papp *et al.*, 1978; Papp & Schmid, 1985).

Chokrakian (Fig. 9)

The Chokrakian takes its name from a lake in the Crimea (Likharev, 1958). It is of Middle Miocene age on regional evidence (see above). Direct biostratigraphic evidence is lacking. The 'Vindobonian Marls' of Northern Iran appear correlative (Stöcklin & Setudehnia, 1971, 1972).

Micropalaeontology. Only non-age-diagnostic, quasi-marine, smaller benthonic foraminifera were recorded by Bogdanowicz (1950b) from the Chokrakian of the western Precaucasus and later by Mamedova (1971) and Azizbekov (1972) from the Chokrakian of Azerbaijan and Popkhadze (1983) for the Chokrakian of western Georgia. These include *Rotalia* [*Ammonia*] ex gr. *beccarii* (smaller benthonic), which has a cosmopolitan distribution and probably ranges no older than Middle Miocene (RWJ's unpublished observations), *Nonion* [*Florilus*] *boueanum* and *Miliolina* [*Quinqueloculina*] *akneriana* sspp., both of which have also been recorded in the Badenian of Central Paratethys (Papp & Schmid, 1985), and *Miliolina caucasica, Sigmoilina tschokrakensis* and *Tschokrakella longiuscula,* all of which are endemic to Eastern Paratethys. The ostracod, *Leptocythere bardrakensis* was recorded by Popkhadze (1984) from the Chokrakian of western Georgia.

Palynology. Only non-age-diagnostic palynomorphs were recorded by Dzhabarova (1973) from the Chokrakian of the Middle Kura Depression. Pollen spectra are characterised by relatively high incidences of herb and shrub taxa including Chenopodiaceae and *Ephedra*. The presence of

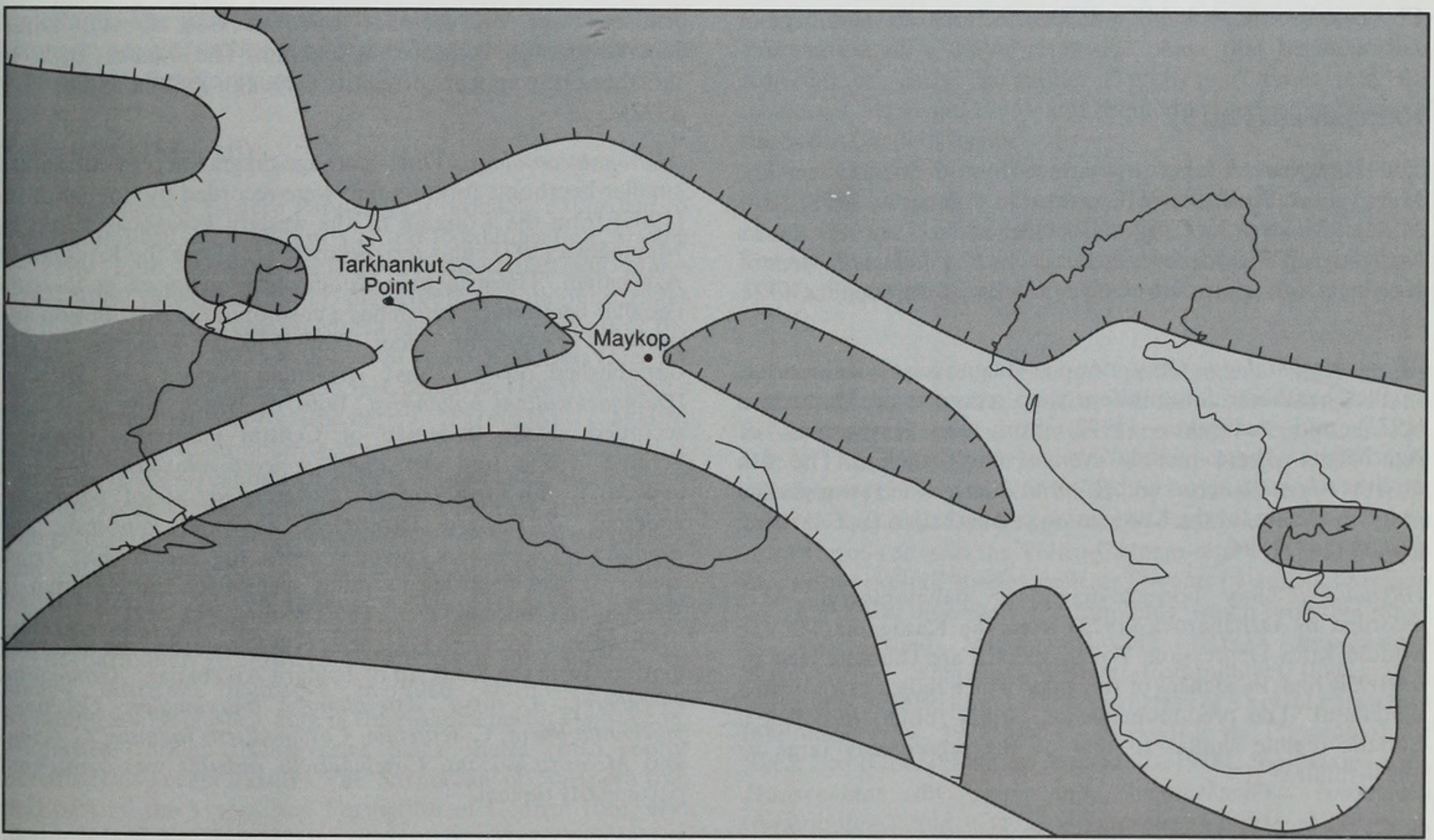

Fig. 8 Palaeogeographic reconstruction, Late Maykopian to Tarkhanian (Late Oligocene to early Middle Miocene). Key as for Fig. 7. The locations of the Maykopian and Tarkhanian stratotypes are indicated.

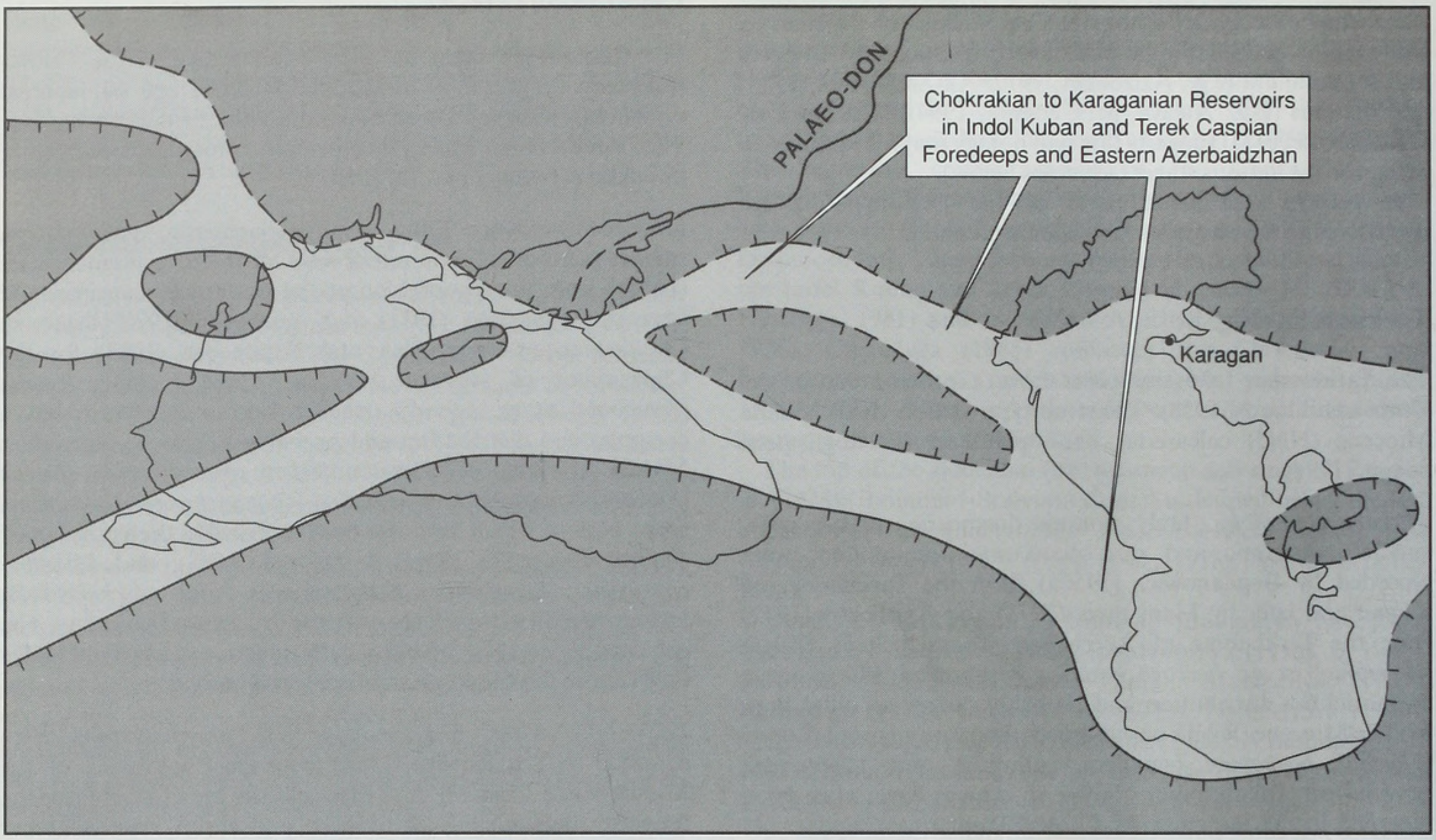

Fig. 9 Palaeogeographic reconstruction, Chokrakian to Karaganian (Middle Miocene). Key as for Fig. 7. The location of the Karaganian stratotype is indicated.

Chenopodiaceae probably indicates the local development of salt-marshes.

Karaganian (Fig. 9)

The Karaganian takes its name from a locality on the Mangyshlak Peninsula in Kazakhstan (Likharev, 1958). It is Middle Miocene on regional evidence (see above). Direct biostratigraphic evidence is lacking. The *Spaniodontella* Beds of Northern Iran appear correlative (Stöcklin & Setudehnia, 1971, 1972).

Micropalaeontology. Only non-age-diagnostic, quasi-marine, smaller benthonic foraminifera were recorded by Mamedova (1971) and Azizbekov (1972) from the Karaganian of Azerbaijan. These include *Nonion bogdanowiczi*. The fish otoliths *Rhombus corius* and *R. corius binagadinica* are regarded as index-species for the Karaganian in Azerbaijan (E.Z. Ateava, pers. comm., 1994).

Palynology. Only non-age-diagnostic palynomorphs were recorded by Dzhabarova (1973) from the Karaganian of the Middle Kura Depression. Pollen spectra are characterised by relatively high incidences of tree taxa, which indicates a forested hinterland. The predominance of *Betula* (birch) indicates a climatic regime similar to that of the present-day taiga or forest-tundra.

Konkian (Fig. 10)

The Konkian takes its name from a river in the Ukraine (a tributary of the Dniepr) (Likharev, 1958). It is of Middle Miocene age on regional evidence (see above). Direct biostratigraphic evidence is lacking. The *Pholas* Beds of Northern Iran appear correlative (Stöcklin & Setudehnia, 1971, 1972).

Micropalaeontology. Only non-age-diagnostic, quasi-marine, smaller benthonic foraminifera were recorded by Bogdanowicz (1965) from the Konkian of the western Precaucasus and by Mamedova (1971) and Azizbekov (1972) from the Konkian of Azerbaijan. These include *Rotalia* [*Ammonia*] ex gr. *beccarii* (smaller benthonic), which has a cosmopolitan distribution and probably ranges no older than Middle Miocene (RWJ's unpublished observations), *Articulina gibbosa* and *Miliolina* [*Quinqueloculina*] *haidingerii*, both of which have also been recorded in the Badenian of Central Paratethys (Papp & Schmid, 1985), and *Articulina elongata konkensis*, *Bulimina konkensis* and *Elphidium nachischevanicus*, all of which are endemic to Eastern Paratethys. *Bulimina konkensis* and *Elphidium kudakoense*, together with the fish otolith *Trigla konkensis*, are regarded as index-species for the Konkian in Azerbaijan (Podobina *et al.*, 1956; Mamedova, 1971).

Shishova (1955) and Gasanova (1965) recorded the following diatoms from the Konkian of Eastern Azerbaijan: *Actinocyclus ehrenbergi*, *A. rafsii*, *Asterolampra marylandica*, *Cocconeis placentula lineta*, *C. scutelum*, *Coscinodiscus radiatus*, *C. oculus* and *Melosira sulcata*. *Coscinodiscus radiatus* was considered particularly typical.

Palynology. Only non-age-diagnostic palynomorphs were recorded by Dzhabarova (1973) from the Konkian of the Middle Kura Depression. Pollen spectra are characterised by relatively high incidences of tree taxa, which indicates a forested

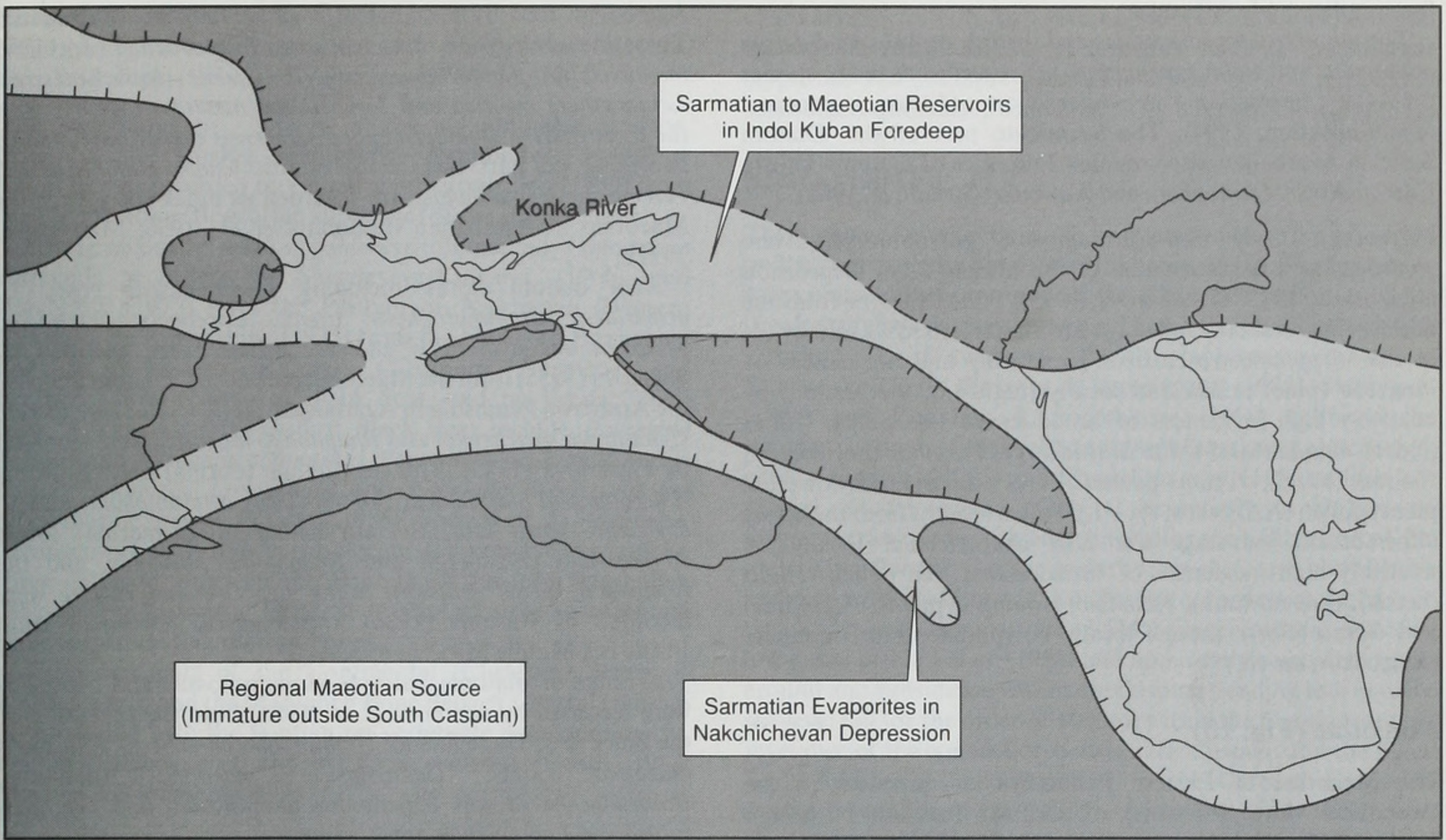

Fig. 10 Palaeogeographic reconstruction, Konkian to Maeotian (late Middle to early Late Miocene). Key as for Fig. 7. The location of the Konkian stratotype is indicated.

hinterland. The predominance of Taxodiaceae (cypresses and swamp-cypresses) indicates a warm-temperate (possibly even subtropical) climatic regime.

Sarmatian (Fig. 10)

The Sarmatian of Eastern Paratethys is probably equivalent to the stratotypical Sarmatian of Central Paratethys (late Middle to early Late Miocene (calcareous nannoplankton zones NN7–NN9) (Meszaros, 1992), planktonic foraminiferal zones N13?–N15), but may also be equivalent to the lower part of the Pannonian (Slavonian) of that area (Late Miocene) (see, for instance, Papp *et al.*, 1974, 1985). Chepalyga (1985) calibrates the Sarmatian of Eastern Paratethys against magnetostratigraphic polarity epochs 10–7, while Zubakov & Borzenkova (1990) calibrate it against epochs 14–9, and Pevzner & Vangengeim (1993) calibrate it against polarity epochs 10–7. The regressive events which characterise the Sarmatian suggest that (within the limits of biostratigraphic control) its base can be correlated with the 10.5Ma (glacio-eustatic) sea-level low-stand of Haq *et al.* (1988).

The Sarmatian of Eastern Paratethys is characterised by areally restricted regressive marginal marine sediments including coarse clastics, and, in the Nakchichevan Depression, evaporites (though transgressive black shales (with source potential) also occur locally). The 'Sarmatian' of Northern Iran and part of the Upper Red Formation of Central Iran, also characterised by clastics and evaporites, appear correlative (Stöcklin & Setudehnia, 1971, 1972). The Sarmatian of Eastern Paratethys has been divided into three sub-stages, which are, from oldest to youngest, Volkhynian, Bessarabian and Chersonian. The 'mid' Sarmatian (Bessarabian) represents the culmination of a major regressive phase that began in late Konkian or 'early' Sarmatian (Volkhynian) times (see, for instance, Chepalyga, 1985), and resulted in the first isolation of the South Caspian Basin.

Details of the Sarmatian stratigraphy of Eastern Paratethys have been discussed by Gasanova (1965), Maisuradze (1971), Mamedova (1971, 1987), Azizbekov (1972), Lupov *et al.* (1972), Dzhabarova (1973), Ali-Zade & Aleskerov (1974), Azizbekova (1974), Paramonova *et al.* (1979) and Pevzner & Vangengeim (1993).

Micropalaeontology. Only non-age-diagnostic (and largely endemic), quasi-marine, smaller benthonic foraminifera and ostracods were recorded from the Sarmatian by Podobina *et al.* (1956), Mamedova (1971, 1987), Voroshilova (1971) and Azizbekov (1972) from Azerbaijan, by Azizbekova (1974) from the Nakchichevan Depression, and by Paramonova *et al.* (1979) from various sites in the Ponto-Caspian region. These include rare cosmopolitan species such as *Streblus* [*Ammonia*] *beccarii* and *Elphidium macellum* (foraminifera), which probably range no older than Middle Miocene (RWJ's unpublished observations), *Elphidium reginum* (foraminifer) (lower part only), which is also found in the Sarmatian of Central Paratethys (Steininger *et al.*, 1976) and (?reworked) in the Pliocene of the Black Sea (Gheorghian, in Ross *et al.*, 1978), *Nonion* div. spp., *Porosononion* div. spp. and *Quinqueloculina consobrina* (foraminifera) and *Cyprideis littoralis, Cythere multistriata, Leptocythere stabilis, Loxoconcha eichwaldi* and *Xestoleberis lutrae* (ostracods). Podobina *et al.* (1956), Mamedova (1971) and Voroshilova (1971) have indicated that the three subdivisions of the Sarmatian in Azerbaijan can be recognised on the basis of foraminifera and ostracods.

The alga *Ovulites sarmaticus* and the fish otoliths *Gadidarum minusculus* and *Gobius sarmaticus* are regarded as index-species for the Sarmatian in Azerbaijan (Ateava, personal communication, 1994). The Sarmatian part of the 'Diatom Suite' in Azerbaijan also contains 23 species of diatoms, chiefly *Coscinodiscus, Licmophora* and *Navicula* (Gasanova, 1965).

Palynology. Only non-age-diagnostic palynomorphs were recorded from the Sarmatian of the Middle Kura Depression (Azizbekov, 1972; Dzhabarova, 1973). Pollen spectra from the middle (Bessarabian) sub-stage are characterised locally by (as in the '*Cryptomactra*-Horizon') relatively high incidences of Pinaceae (pine) pollen and locally (higher in the section) by relatively high incidences of broad-leaved tree pollen (*Alnus* (alder), *Betula* (birch), *Carya* (hickory), *Carpinus* (hornbeam), *Corylus* (hazel), *Juglans* (walnut)) and angiosperm (flowering plant) pollen (Azizbekov, *op. cit.*). Pollen spectra from the upper (Chersonian) sub-stage are also characterised locally by relatively high incidences of broad-leaved tree pollen (*Fagus* (beech), *Quercus* (oak), *Taxodium* (swamp-cypress), *Tilia* (lime) and *Ulmus* (elm)), though locally Polypodiaceae predominate (Azizbekov, *op. cit.*).

Maeotian (Fig. 10)

The Maeotian of Eastern Paratethys is equivalent to the Pannonian (Late Miocene) of Central Paratethys (though possibly only the upper part thereof (Serbian) (see, for instance, Papp *et al.* (1974, 1985) and Pevzner & Vangengeim (1985b)). Rögl (1985a) calibrates it against calcareous nannoplankton Zone NN10. Chepalyga (1985) calibrates it against magnetostratigraphic polarity epochs 6–5, while Zubakov & Borzenkova (1990) calibrate it against polarity epochs 10–7. Krakhmalnaya *et al.* (1993) have recently described a succession at Novaya Emetovka on the Black Sea coast with a good Maeotian mammal fauna which they calibrate against polarity epochs 6 and 5. The Maeotian is represented by a transgressive-regressive cycle. It is locally characterised by black shales (with hydrocarbon source potential). The Maeotian sea was probably characterised by reduced salinity. Similar environmental conditions evidently obtained in the Pannonian of Central Paratethys, where benthonic foraminiferal assemblages are of quasi-marine (brackish water) aspect (*Ammobaculites, Ammomarginulina, Miliammina, Trochammina*) (Papp *et al.*, 1985).

Details of Maeotian stratigraphy have been discussed by Shishova (1955), Gasanova (1965), Bogdanowicz (1967, 1969, 1974), Mamedova (1971), Voroshilova (1971), Azizbekov (1972), Lupov *et al.* (1972), Popkhadze (1977), Paramonova *et al.* (1979), Ananova *et al.* (1985), Ali-Zade *et al.* (1986), Rasulov (1986), Maisuradze (1988), Naidina (1988) and Ateava (personal communication, 1994).

Micropalaeontology and Nannopalaeontology. Only non-age-diagnostic, quasi-marine, smaller benthonic foraminifera were recorded by Bogdanowicz (1967, 1969) from the Maeotian of the Kuban and Western Precaucasus and by Paramonova *et al.* (1979) from the Maeotian of various sites in the Ponto-Caspian. These include *Elphidium macellum*, which has a cosmopolitan distribution and probably ranges no older than Middle Miocene (RWJ's unpublished observations) and *Nonion* div. spp.

Some stratigraphically and/or palaeoenvironmentally significant ostracods were recorded by Azizbekov (1972) from Azerbaijan and by Popkhadze *et al.* (1980) from Abkhazia. These include *Leptocythere biplicata, L. meotica, Loxoconcha meotica, L. tamarindus* and *L. viridis* (quasi-marine). *Leptocythere meotica* and *Loxoconcha meotica*, together with the foraminifera *Quinqueloculina sulacensis* (lower part) *and Q. ludwigi* (upper part) and the fish otoliths *Clupea gidjakensis* and *Percidarum sigmalinoides* are regarded as index-species for the Maeotian in Azerbaijan (Podobina *et al.*, 1956; Mamedova, 1971).

Rich diatom floras including *Coscinodiscus gigas, C. oclisirides, Grammatophora azens, Cocconeis heteroidea, Melosira archotecturallis* and *M. sulcata* were recorded by Shishova (1955) from the Maeotian part of the 'Diatom Suite' of the Apsheron Peninsula in Azerbaijan. *Actinocyclus ehrenbergii, Cymatosira sovtchenkoi* and *Rhaphoneis maeotica* were recorded by Gasanova (1965). The stenohaline (normal marine) forms *Asterolampha marylanica, Coscinodiscus asteromphalus* and *C. lewisanus sensu lato*, the euryhaline (quasi-marine) forms *Actinocyclus ehrenbergii* and *Rhapolodia musculus*, and the freshwater forms *Amphora ovalis* and *Diatoma vulgare* were recorded by Rasulov (1986). *Coscinodiscus lewisianus sensu stricto* is a Middle Miocene species.

A range of diatoms, calcareous nannofossils and ostracods were recorded by Ananova *et al.* (1985) from the Maeotian of the Black Sea. These include *Actinocyclus ehrenbergi, Rhaponeis maeotica* and *Thalassiosira maeotica* (diatoms), *Braarudosphaera* spp. (calcareous nannofossil) and *Cyprideis torosa* and *Leptocythere* spp. (ostracods).

Palynology. Only non-age-diagnostic palynomorphs have been recorded from the Maeotian, and only the acritarch *Micrhystridium* sp. was recorded by Ananova *et al.* (1985) from the Maeotian of the Black Sea. Pollen spectra from the Late Maeotian of the Task-Sunzhenskii Region are characterised by relatively high incidences of Asteraceae and Polygonaceae (herbs), *Ephedra* (shrubs) and Gramineae (grasses) (Naidina, 1988). This indicates an open, sparsely forested hinterland and an arid climatic regime similar to that of the present-day steppe or semi-desert. The locally relatively high incidences of Gleicheniaceae (ferns) and Lycopodiaceae (club-mosses) indicate local development of conditions similar to those of the present-day tundra, forest-tundra or mountain belt. The presence of Chenopodiaceae probably indicates local development of salt-marshes.

Pontian

The Pontian takes its name from the ancient name for the Black Sea. It is essentially regressive (though it also includes an overstepping transgressive unit at the base), and is characterised regionally by marginal marine coarse clastics and shallow marine carbonates and locally (Babajan Formation, Bosporian Sub-Stage) by evaporites. Chepalyga (1985) calibrates the Pontian against magnetostratigraphic polarity epoch 4 (Gilbert), while Zubakov & Borzenkova (1990) calibrate it against polarity epochs 6–5. We correlate the Pontian evaporites against those of the stratotypical Messinian, which can be calibrated against magnetostratigraphic polarity epoch 5 (Zubakov & Borzenkova, 1990).

Details of the Pontian stratigraphy of Eastern Paratethys have been discussed by, among others, Sveier (1949), Mandelstam *et al.* (1962), Sheydayeva-Kuliyeva (1966), Agalarova (1967), Vekilov *et al.* (1969), Ramishvili (1969), Rozyeva (1971), Azizbekov (1972), Lupov *et al.* (1972), Chelidze (1973), Karmishina (1975), Vekua (1975), Krstic (1976), Shchekina (1979), Imnadze & Karmishina (1980), Ali-Zade *et al.* (1986), Sirenko & Turlo (1986) and Yagmurlu & Helvaci (1994).

Micropalaeontology. Only the non-age-diagnostic, quasi-marine, smaller benthonic foraminifer *Elphidium stellatum* was recorded by Imnadze & Karmishina (1980) from the Late Pontian (Bosporian sub-stage) of the Black Sea.

Stratigraphically and/or palaeoenvironmentally significant ostracods recorded by Sheydayeva-Kuliyeva (1966) and Azizbekov (1972) from the Pontian of Azerbaijan (Western Caspian), by Karmishina (1975) from the Northern Precaspian and South-Eastern Kalmyk (Northern Caspian) and Prechernomore (Northern Black Sea), and by Vekua (1975) from Abkhazia (north-eastern Black Sea) include *Bakunella dorsoacuata, Caspiolla acronasuta, Pontoniella acuminata* and *P. loczyi. Bakunella dorsoacuata* and *Caspiolla acronasuta* are quasi-marine species (Yassini, 1986). Species of *Leptocythere, Loxoconcha* and *Xestolebris* also occur. It is possible to recognise three ostracod zones in the Pontian of Eastern Azerbaijan (Sheydayeva-Kuliyeva, 1966). It is also possible to recognise three corresponding mollusc zones.

The lower part of the Continental (Cheleken) Series of Northern Iran and the Maragheh Bone Beds of Central Iran can be correlated with the Pontian on vertebrate palaeontological, limited malacological and ostracod evidence (Faridi, 1964; Stöcklin & Setudehnia, 1971, 1972).

Palynology. Only non-age-diagnostic palynomorphs have been recorded from the Pontian. Pollen spectra from the Pontian of Georgia are characterised by relatively high incidences of tropical elements such as *Nypa* (palm) (Ramishvili, 1969). Those from the Late Pontian (Bosporian sub-stage) of the Ukraine are characterised initially by thermophilic (warm-temperate) and hydrophilic (moisture-loving) elements such as Taxodiaceae (cypresses and swamp-cypresses) and later by arid steppe and semi-desert elements (Shchekina, 1979; Sirenko & Turlo, 1986).

Kimmerian (Fig. 11)

The Kimmerian takes its name from an ancient tribe who lived on the shores of the Black Sea (Likharev, 1958). The Dacian (a stage name sometimes used in the Black Sea region) and the 'Eoakchagylian' (a stage name used in the Caspian Sea region by Zubakov & Borzenkova (1990)) appear synonymous. Semenenko (1979), Pevzner & Vangengeim (1985), Skalbdyna (1985) and Zubakov & Borzenkova (1990) calibrate the Kimmerian against magnetostratigraphic polarity epochs 5–4, while Chepalyga (1985) and Chepalyga *et al.* (1985) calibrate it against polarity epoch 4 (Gilbert). Essentially on the basis of magnetostratigraphic evidence (including the calibration of the underlying Pontian against polarity epoch 5 (see above)), we have tentatively calibrated the major unconformity at the base of the Kimmerian against the 5.5Ma glacio-eustatic sea-level low-stand of Haq *et al.* (1988) and apparently coincident uplift around and subsidence within the Caspian (leading to a massive sea-level fall (of the order of 1000m) within the Caspian and the severance of the connection between the Caspian and the Black Sea). Additional unconformities in the Caspian succession cannot be confidently calibrated against any of the third-order glacio-eustatic sea-level low-stands on the Haq *et al.* chart, and may be associated with higher frequency glacio-eustatic low-stands or local tectonic events. Due partly to tectono-eustatic effects (see above), and partly to climatic effects

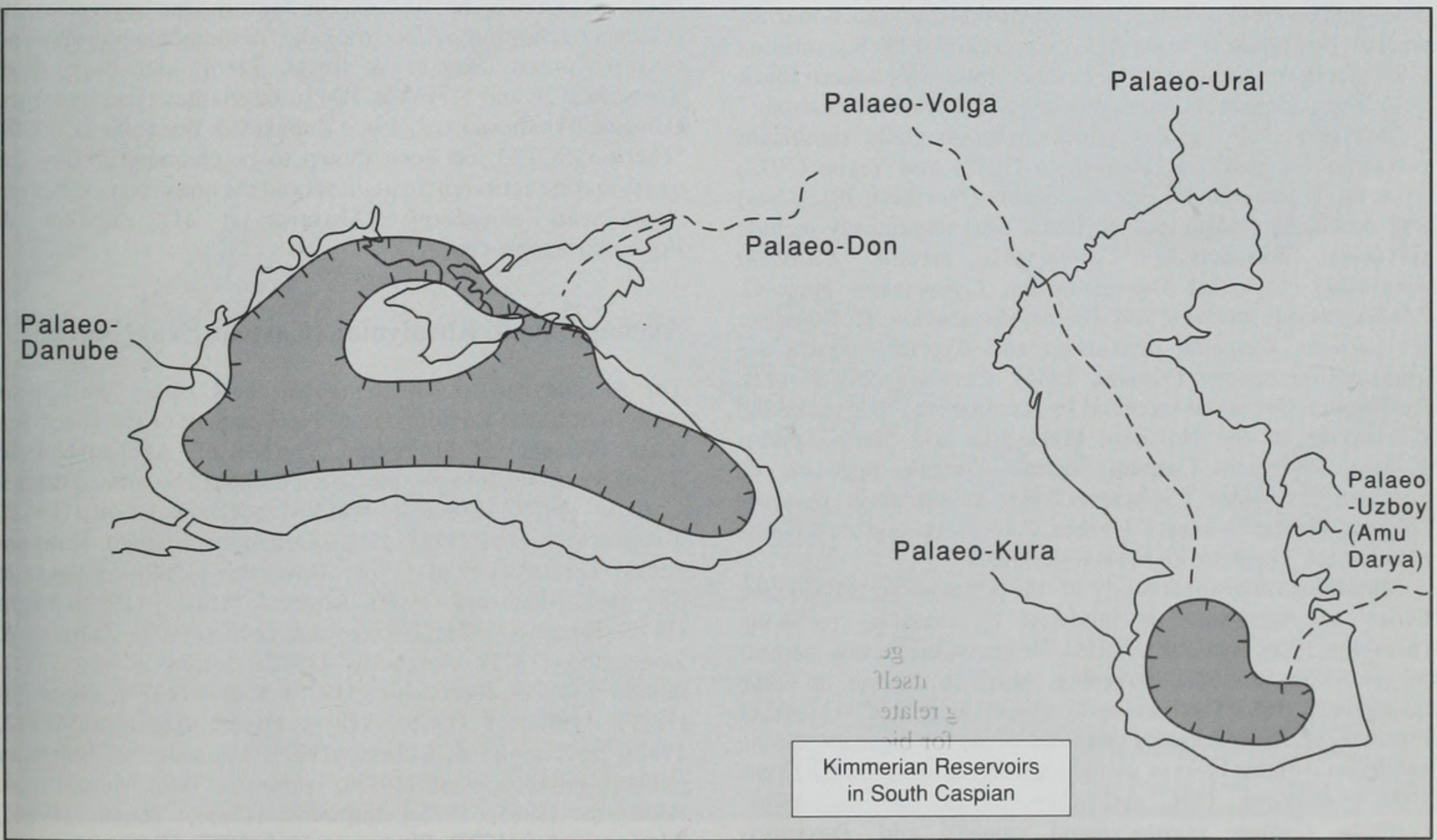

Fig. 11 Palaeogeographic reconstruction, Dacian/Kimmerian (latest Miocene to Pliocene). Key as for Fig. 7.

(an excess of evaporation over precipitation) and a change in the drainage system (with rivers formerly flowing into Paratethys captured by rejuvenated rivers flowing into the Mediterranean, where base-level had fallen considerably during the Messinian salinity crisis (see, for instance, Hsu (1983)), the level and the areal extent of the Caspian 'athalassic lake' were drastically reduced during the Kimmerian. Palaeontological evidence points to a stratigraphically upward reduction in salinity. The basal Kimmerian contains a quasi-marine ostracod fauna (characterised by *Cyprideis littoralis/torosa*) that appears correlative with that of the Messinian 'Lago Mare' facies in the Mediterranean.

In Azerbaijan, the Kimmerian is characterised by several thousand metres (thicknesses of around 4km are typical around the Apsheron Peninsula) of principally Palaeo-Volga-derived, regressive marginal and non-marine coarse clastics comprising the main ('Productivnaya Tolsha' = 'Productive Series') reservoirs in several billion-barrel oil-fields (Khain *et al.*, 1937; Ismailov and Idrisov, 1963; Ismailov *et al.*, 1972; Nikishin, 1981; Babayan, 1984; Kerimov *et al.*, 1991; Narimanov, 1993). The sedimentology of this succession is discussed in detail by Reynolds *et al.* (in press). Constituent lithostratigraphic units include, in ascending stratigraphic order, the Kalin or Kala, Podkirmakina (Pre-Kirmaky Sand (PK)), Kirmakina (Kirmaky Sand (KS)), Nadkirmakina (Post-Kirmaky Sand and Post-Kirmaky Clay (NKP and NKG)), Pereriva, Balakhany, Sabunchi and Surakhany Suites.

Details of Kimmerian stratigraphy have been discussed by, among others, Ali-Zade (1946), Khalilov (1946), Sveier (1949), Agalarova (1956), Mandelstam *et al.* (1962), Rozyeva (1971), Azizbekov (1972), Lupov *et al.* (1972), Ali-Zade (1974), Karmishina (1975), Vekua (1975), Ananova *et al.* (1985), Sirenko & Turlo (1986) and Yassini (1986).

Micropalaeontology Only non-age-diagnostic, quasi-marine, smaller benthonic foraminifera were recorded by Karmishina (1975) from the Kimmerian of Prechernomore (Northern Black Sea). These include *Ammonia beccarii* and *Elphidium incertum*.

Stratigraphically and/or palaeoenvironmentally significant ostracods recorded by Karmishina (1975) and Vekua (1975) from the Kimmerian of Prechernomore (Northern Black Sea) and Abkhazia (North-eastern Black Sea) respectively include *Bakunella dorsoacuata, Caspiocypris labiata, Caspiolla acronasuta, Cyprideis littoralis/torosa, Leptocythere bosqueti, Mediocythereis apatoica* and *Pontoniella acuminata. Bakunella dorsoacuata, Caspiolla acronasuta* and *Cyprideis torosa* are quasi-marine species (Yassini, 1986). *Caspiocypris labiata* is fresh-water. Ostracods recorded by Karmishina (1975) from the Kimmerian of the Northern Precaspian and South-Eastern Kalmyk (Northern Caspian) include *Candona angulata, C. neglecta, C. rostrata, Cyclocypris laevis, Cypria arma, Eucypris naidinae, Ilyocypris bradyi, I. gibba, I. serpulosa* and *Zonocypris membranae.* These are all fresh-water forms.

Microbiostratigraphic study of the Kimmerian 'Productive Series' in Azerbaijan is hindered by massive reworking (Khalilov, 1946; Agalarova, 1956). However, the general pattern of reworking indicates unroofing, which in itself is of some stratigraphic value (with pulses of reworking related to sea-level low-stands). Moreover, the potential exists for biostratigraphic subdivision on the basis of ostracods (see, for instance, Khalilov, 1946; Agalarova, 1956; Azizbekov, 1972). The Kala Suite contains *Cythere* [*Leptocythere*] *camellii* and *Paracypris liventalina* (quasi-marine), the Kirmakina Suite *Cythere* [*Leptocythere*] *cellula, C.* [*Cyprideis*] *littoralis/torosa, C. olivina, C.* [*Leptocythere*] *praebacuana, Hemicythere pontica* and *Loxoconcha djabaroffi* (quasi-marine), the Pereriva Suite *Cyprideis littoralis/torosa* (quasi-marine), the Balakhany Suite *Cythere* [*Leptocythere*] *praebacuana, Loxoconcha alata, L. eichwaldi* and *Xestoleberis lutrae* (quasi-marine), the Sabunchi Suite no *in situ* ostracods, and the Surakhany Suite *Eucypris* (fresh-water) and *Leptocythere* and *Loxoconcha* (quasi-marine).

The Krasnotsvetnaya ('Red-Coloured') Series of Turkmenia can be correlated with the Kimmerian on ostracod evidence (Agalarova, 1956; Lupov *et al.*, 1972). The lowermost part contains *Bakunella, Caspiolla, Pontoniella* and *Xestoleberis* and is of Pontian aspect, while the uppermost part contains *Leptocythere* and *Limnocythere* and is of Akchagylian aspect.

The upper part of the Continental (Cheleken) Series of Northern Iran can be correlated with the Kimmerian on vertebrate palaeontological, limited malacological and ostracod evidence (Faridi, 1964; Stöcklin & Setudehnia, 1971, 1972). The Lacustrine Fish Beds of Central Iran, locally characterised by volcanic ash bands, can also be tentatively correlated with the Kimmerian (Stöcklin & Setudehnia, *op. cit.*).

Nannopalaeontology. Stratigraphically significant calcareous nannofossils recorded by Zubakov & Borzenkova (1990) from the Kimmerian include *Discoaster quinqueramus* (NN11) (?reworked), *Ceratolithus acutus* ('late' NN12) and *C. rugosus* (NN13–?NN19).

Palynology. Only non-age-diagnostic palynomorphs have been recorded from the Kimmerian. However, at least theoretically, climatostratigraphy ought to have some utility in the stratigraphic subdivision of the 'Productive Series' (with a number of superclimathems discernable on the basis of different pollen spectra). Indeed, the results of preliminary analyses have shown pollen spectra from 'Thermo'-SCT27 in the Ukraine to be characterised by broad-leaved and subtropical forest elements (*Castanea* (chestnut), *Rhus* (rue) and Taxodiaceae (cypress and swamp-cypress) (Sirenko & Turlo, 1986), and those from 'Cryo'-SCT26 and 'Cryo'-SCT24 to be characterised by steppe elements (Ananova *et al.*, 1985; Zubakov & Borzenkova, 1990). 'Thermo'-SCT23 has been shown to be characterised by the quasi-marine acritarch *Sigmailina* (and the quasi-marine diatom *Actinocyclus ehrenbergi*) (Ananova *et al.*, Zubakov & Borzenkova, *opp. cit.*).

Akchagylian to Khvalynian (Caspian Sea) (Fig. 12)

The Akchagylian to Khvalynian of the Caspian Sea appear equivalent to the Kuyalnikian to Neoeuxinian of the Black Sea (Late Pliocene to Holocene). Details of Akchagylian to Khvaklynian stratigraphy have been discussed by, among others, Livental (1929), Sveier (1949), Mandelstam *et al.* (1962), Yakhimovich *et al.* (1965, 1984), Dzhabarova (1966), Kuliyeva (1968), Dmitriyev *et al.* (1969), Rayevskiy (1969), Sultanov & Sheydayeva-Kuliveya (1969), Aliyev & Aliyeva (1970), Kopp (1970), Rozyeva (1971), Ushakova & Ushko (1971), Zubakov & Kochegura (1971), Azizbekov (1972), Lupov *et al.* (1972), Ananova (1974), Karmishina (1975), Kaplin (1977), Trubikhin (1977), Fedkovich (1978), Veliyev (1980), Abramova (1982, 1985), Semenenko & Lulieva (1982), Mamedov & Rabotina (1984a), Aliyulla *et al.* (1985), Ivanova (1985), Mamedov & Aleskerov (1985, 1986), Sultanov (1985), Yassini (1986), Aleskerov *et al.* (1987), Bludorova *et al.* (1987), Zhidovinov *et al.* (1987), Naidina (1988), Ali-Zade & Aliyeva (1989), Yanko (1990a–b, 1991), Trubikhin *et al.* (1991) and Mamedova (1993).

Akchagylian (Fig. 12)

The Akchagylian takes its name from a locality near Krasnovodsk on the southern shores of the Gulf of Karabogaz in Western Turkmenia (Likharev, 1958). It appears equivalent to the Kuyalnikian of the Black Sea. Zubakov & Borzenkova (1990) calibrate it against magnetostratigraphic polarity epochs 4 (Gilbert) or 3 (Gauss) to 2 (Matuyama). The Akchagylian is transgressive and is represented by marine shales (constituting an important regional seal in the South Caspian). The transgressions within the Akchagylian temporarily re-established marine connections to the world's oceans. Calcareous nannoplankton data (see below) indicates that they may correspond to the 3.4Ma, 2.7Ma and 2.0Ma maximum flooding surfaces of Haq *et al.* (1988).

Details of Akchagylian stratigraphy have been discussed by, among others, Ali-Zade (1936), Yakhimovich *et al.* (1965, 1983), Dzhabarova (1966), Ali-Zade (1969), Dmitriyev *et al.* (1969), Sultanov & Sheydayeva-Kuliveya (1969), Aliyev & Aliyeva (1970), Ushakova & Ushko (1971), Zubakov & Kochegura (1971), Azizbekov (1972), Lupov *et al.* (1972), Ananova (1974), Karmishina (1975), Trubikhin (1977), Fedkovich (1978), Sultanov (1979), Semenenko & Lulieva (1982), Mamedov & Rabotina (1984a), Bludorova *et al.* (1987), Zhidovinov *et al.* (1987), Naidina (1988) and Benyamovskoy & Naidina (1990).

Micropalaeontology. Only non-age-diagnostic smaller benthonic foraminifera were recorded by Yakhimovich *et al.* (1965), Sultanov & Sheydayeva-Kuliyeva (1969) and Karmishina (1975) from the Akchagylian of the Volga-Urals Region, Azerbaijan, and the Northern Precaspian and South-Eastern Kalmyk (Northern Caspian) respectively. These include *Ammonia beccarii*, *Bolivina* ex gr. *advena*, *B. aksaica*, *B. floridana*, *Buccella* sp., *Cassidulina crassa*, *C. oblonga*, *Cassidulinita prima*, *Cibicides lobatulus*, *Discorbis arculus*, *D. multicameratus*, *D. orbicularis*, *D. pliocenicus*, *Elphidium incertum*, *E. kudakoense*, *E. macellum*, *E. subarcticum*, *Nonion aktschagylicus* and *Quinqueloculina* spp. *Bolivina*, *Cibicides* and *Discorbis* are near-normal marine genera, while the remainder are quasi-marine.

Stratigraphically and/or palaeoenvironmentally significant ostracods recorded by Sultanov & Sheydayeva-Kuliyeva (1969) and Karmishina (1975) from the Akchagylian of Azerbaijan, and the Northern Precaspian and South-Eastern Kalmyk (Northern Caspian) respectively include *Aglaiocypris chuzchievae*, *Candona convexa*, *Ilyocypris gibba* and *Leptocythere verrucosa*. *Aglaiocypris*, *Candona* and *Ilyocypris* are fresh-water forms, while *Leptocythere* is quasi-marine.

In Azerbaijan, the Akchagylian (Akchagyl Suite) contains a diverse marine ostracod and molluscan fauna (Livental, 1929; Ali-Zade, 1954; Sultanov & Sheydayeva-Kuliyeva, 1969). On the Apsheron Peninsula, it can be divided into three units on the basis of ostracods. Freshwater forms (*Candona*, *Eucypris*, *Ilyocypris*, *Limnocythere*) characterise the lower unit, marine and quasi-marine forms the middle and upper units.

Stratigraphically and/or palaeoenvironmentally significant diatoms recorded by Ushakova & Ushko (1971) from the Akchagylian to Apsheronian of the Krasnovodsk Peninsula in Western Turkmenia include *Actinocyclus ehrenbergi* ssp. *ralfsii*, *Campylodiscus noricus*, *C. noricus* ssp. *hibernica*, *Cocconeis scutellum*, *Coscinodiscus argus*, *Cymbatopleura elliptica*, *Diploneis bombus*, *D. domblittensis*, *D. fusca* ssp. *pervasta*, *D. rombica*, *Epithemia turgida*, *Grammatophora oceanica*, *Melosira*

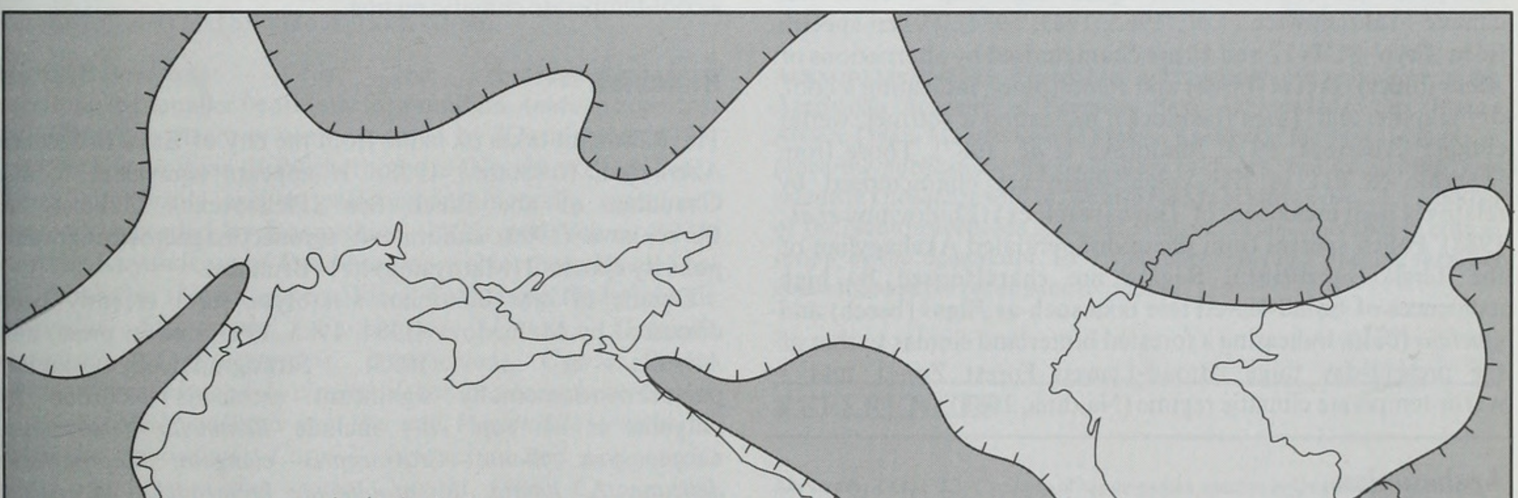

Fig. 12 Palaeogeographic reconstruction, Akchagylian/Kuyalnikian (Late Pliocene). Key as for Fig. 7. The location of the Akchagylian stratotype is indicated.

arenaria, M. scabrosa, M. sulcata, Navicula lyra ssp. *elliptica, Nitzchia cocconeiformis, Rhopalodia parallella, Surirella striatula, Terpsinoe musica* and *Triceratium* sp. *Campylodiscus noricus, C. noricus* ssp. *hibernica, Diploneis domblittensis, D. rombica, Melosira arenaria, M. scabrosa, M. sulcata* and *Rhopalodia parallella* are exclusively fresh-water forms, while the remainder are quasi-marine.

The Akchagyl Beds of Northern Iran can be correlated with the stratotypical Akchagylian on ostracod evidence (Faridi, 1964; Stöcklin & Setudehnia, 1971, 1972). Various volcanics in Central Iran can also be tentatively correlated with the Akchagylian (Stöcklin & Setudehnia, *op. cit.*).

Nannopalaeontology. Stratigraphically significant calcareous nannofossils recorded by Semenenko & Lulieva (1982) from the Akchagylian include *Discoaster brouweri* (NN8?–NN18) (no younger than 1.89Ma), *D. pentaradiatus* (NN9?–NN17) (no younger than 2.33–2.43Ma) and *Reticulofenestra pseudoumbilica* (NN7?–NN15). These are similar to nannoflora found in the Kuyalnikian of the Black Sea region by Semenko & Pevzner (1979), and suggest a link between the two basins at this time.

Palynology. Only non-age-diagnostic palynomorphs have been recorded from the Akchagylian. Pollen spectra from 'Cryo'-SCT14 (and 'Thermo'-SCT15) are characterised by high incidences of *Abies* (fir), indicating a forested hinterland similar to that of the present-day taiga, and a cool, wet climate (Bludorova *et al.*, 1987). Those from 'Thermo'-SCT13 are characterised by *Abies* (fir), *Acer* (maple), *Carpinus* (hornbeam) and *Ulmus* (elm), indicating a warmer climate (Bludorova *et al.*, *op. cit.*). Pollen spectra from 'Cryo'-SCT14 in the Volga-Urals Region are characterised by relatively high incidences of Lycopodiaceae (club-mosses), again indicating a cool, wet climate (Yakhimovich *et al.*, 1965, 1983, 1984). Pollen spectra from 'Cryo'-SCTs 12 and 10 are characterised by alternations of *Alnus* (alder), *Betula* (birch) and *Pinus* (pine), indicating a cool, dry climate, and *Tsuga* (hemlock), indicating a warmer, wetter climate (Ananova, 1974; Bludorova *et al.*, 1987). Those from 'Thermo'-SCT11 in the Volga Basin are characterised by relatively high incidences of *Tsuga* (hemlock) (Zhidovinov *et al.*, 1987). Pollen spectra from the undifferentiated Akchagylian of the Tersko-Sunzhenskii Region are characterised by high incidences of broad-leaved tree taxa such as *Fagus* (beech) and *Quercus* (oak), indicating a forested hinterland similar to that of the present-day taiga (Broad-Leaved Forest Zone), and a warm-temperate climatic regime (Naidina, 1988).

Apsheronian

The Apsheronian takes its name from the Apsheron Peninsula in Eastern Azerbaijan (Likharev, 1958). It appears equivalent to the Gurian of the Black Sea (Pleistocene). Zubakov & Borzenkova (1990) calibrate it against magnetostratigraphic polarity epoch 2 (Matuyama). The Apsheronian is essentially regressive in character. Marine connections between the Caspian and the Black Sea were probably only intermittently developed.

Details of Apsheronian stratigraphy have been discussed by Livental (1929), Sultanov (1964), Kuliyeva (1968), Ushakova & Ushko (1971), Azizbekov (1972), Lupov *et al.* (1972), Ali-Zade (1973), Ivanova (1985), Zhidovinov *et al.* (1987) and Mamedova (1988).

Micropalaeontology. Stratigraphically and/or palaeoenvironmentally significant ostracods recorded by Kuliyeva (1968) and Mamedova (1984, 1988) from the Apsheronian of the Baku Archipelago in Azerbaijan include *Bakunella dorsoacuata, Candona albicans, Caspiocypris lyrata, C. rotulata, C. sinistrolyrata, Caspiolla acronasuta, C. gracilis, Eucypris membranae, Leptocythere andrusovi, L. caspia, L. fragilis, L. multituberculata, L. propinqua, L. quinquetuberculata, L. turquianica, L. verrucosa, Loxoconcha eichwaldi, L. gibboida, L. impressa* and *Trachyleberis azerbaidzhanica. Bakunella, Caspiolla, Leptocythere, Loxoconcha* and *Trachyleberis* are quasi-marine forms, while *Candona, Caspiocypris* and *Eucypris* are fresh-water (see, for instance, Yassini, 1986). At least six assemblage zones can be recognised on the basis of ostracods (D.N. Mamedova, pers. comm., 1994). These will be discussed in a forthcoming paper (Mamedova, in press) (see also Mamedova, 1988).

Stratigraphically and/or palaeoenvironmentally significant diatoms recorded by Ushakova & Ushko (1971) from the Akchagylian to Apsheronian of the Krasnovodsk Peninsula in Western Turkmenia are listed under 'Akchagylian' above. They include exclusively fresh-water, fresh-water to brackish, and brackish to near-normal marine forms.

The Apsheron Beds of Northern Iran can be correlated with the stratotypical Apsheronian on ostracod evidence (Faridi, 1964; Stöcklin & Setudehnia, 1971, 1972).

Palynology. Only non-age-diagnostic palynomorphs have been recorded from the Apsheronian. Pollen spectra described by Ivanova (1985) from the Apsheronian of Western Turkmenia and by Zhidovinov *et al.* (1987) from the Apsheronian of the Volga Basin are characterised by relatively high incidences of non-tree taxa. This indicates an open, sparsely forested hinterland similar to the present-day steppe or forest-steppe, and a cool-temperate climatic regime.

Bakunian

The Bakunian takes its name from the city of Baku in Eastern Azerbaijan (Likharev, 1958). It appears equivalent to the Chaudian of the Black Sea (Pleistocene). Zubakov & Borzenkova (1990) calibrate it against magnetostratigraphic polarity epochs 2 (Matuyama) to 1 (Brunhes).

Details of the Bakunian stratotype have recently been discussed by Mamedova (1984, 1985, 1993, and in press) and Aliyulla *et al.* (1985). Stratigraphically and/or palaeoenvironmentally significant ostracods recorded by Aliyulla *et al.* (*op. cit.*) include *Bakunella dorsoacuata, Caspiocypris filona, Graviacypris elongata, Leptocythere delicata, L. lunata, L. propinqua, Loxoconcha endocarpa, Pseudostenocypria asiatica* and *Xestoleberis ementis. Bakunella, Graviacypris, Leptocythere, Loxoconcha* and *Xestoleberis* are quasi-marine forms, while *Caspiocypris* and *Pseudostenocypria* are fresh-water (see, for instance, Yassini, 1986). Four assemblage zones can be recognised on the basis of ostracods (Mamedova, in press).

The Baku Formation of Northern Iran can be correlated with the stratotypical Bakunian on ostracod evidence (Faridi, 1964; Stöcklin & Setudehnia, 1971, 1972).

Khazarian, Girkan and Khvalynian

The Khazarian takes its name from an ancient tribe who lived in the area between the Don and Volga Rivers, and the Girkan(ian) and Khvalynian take theirs from ancient names for the Caspian

Sea (Likharev, 1958). The Khazarian, Girkan and Khvalynian appear equivalent to the Uzunlarian, Karangatian and Neoeuxinian respectively of the Black Sea (Pleistocene-Holocene). Zubakov & Borzenkova (1990) calibrate the Khazarian, Girkan and Khvalynian against magnetostratigraphic polarity epoch 1 (Brunhes).

Kuyalnikian to Neoeuxinian (Black Sea) (Fig. 12)

The Kuyalnikian to Neoeuxinian of the Black Sea appear equivalent to the Akchagylian to Khvalynian of the Caspian (Late Pliocene to Holocene). Details of Kuyalnikian to Neoeuxinian stratigraphy have been discussed by Wall & Dale (1973), Karmishina (1975), Vekua (1975), Kaplin (1977), Shikmus *et al.* (1977), Schrader (1979), Semenenko & Pevzner (1979), Shatilova (1984), Sirenko & Turlo (1986), Yanko (1990a–b, 1991), Balabanov *et al.* (1991) and Trubikhin *et al.* (1991a–b).

Kuyalnikian (Fig. 12)

The Kuyalnikian takes its name from a locality on the Danube Delta (Likharev, 1958). The Romanian appears synonymous. It appears equivalent to the Akchagylian of the Caspian. Zubakov & Borzenkova (1990) calibrate it against magnetostratigraphic polarity epochs 3 (Gauss) to 2 (Matuyama).

The Kuyalnikian/Akchagylian represents a major transgressive episode when Eastern Paratethys was reconnected with the world oceans (Fig. 12). During this time, marine plankton were introduced into Eastern Paratethys enabling calibration to global datums.

Details of Kuyalnikian stratigraphy have been discussed by Karmishina (1975), Vekua (1975), Semenenko & Pevzner (1979), Shatilova (1984) and Sirenko & Turlo (1986).

Micropalaeontology. Only the non-age-diagnostic, quasi-marine, smaller benthonic foraminifera *Ammonia beccarii* and *Elphidium incertum* were recorded by Karmishina (1975) from the Kuyalnikian of Prechernomore (Northern Black Sea).

Stratigraphically and/or palaeoenvironmentally significant ostracods recorded by Karmishina (1975) and Vekua (1975) from the Kuyalnikian of Prechernomore (Northern Black Sea) and Abkhazia (North-eastern Black Sea) respectively include *Bakunella dorsoacuata, Caspiocypris labiata, Caspiolla acronasuta, Cryptocyprideis bogatschovi, Cypria arma, Leptocythere andrusovi, L. circumsulcata, Loxoconcha eichwaldi, L. petasa, Mediocythereis apatoica* and *Pontoniella acuminata. Bakunella dorsoacuata, Caspiolla acronasuta* and *Loxoconcha petasa* are quasi-marine species (Yassini, 1986). *Caspiocypris acronasuta* and *Cypria arma* are fresh-water.

Nannopalaeontology. Stratigraphically significant calcareous nannofossils recorded by Semenenko & Pevzner (1979) from the Kuyalnikian include *Discoaster pentaradiatus* (NN9?–NN17) and *Reticulofenestra pseudoumbilica* (NN7?–NN15).

Palynology. Only non-age-diagnostic palynomorphs have been recorded from the Kuyalnikian. Pollen spectra from 'Thermo'-SCT15 are characterised by polydominance (Shatilova, 1984; Sirenko & Turlo, 1986).

Gurian

The Gurian takes its name from an ancient province of what is now Western Georgia (Likharev, 1958). It appears equivalent to the Apsheronian of the Caspian (Pleistocene). Zubakov & Borzenkova (1990) calibrate it against magnetostratigraphic polarity epoch 2 (Matuyama).

Chaudian

The Chaudian takes its name from a promontory on the Kerch Peninsula (Crimea) (Likharev, 1958). It appears equivalent to the Bakunian of the Caspian (Pleistocene). Zubakov & Borzenkova (1990) calibrate it against magnetostratigraphic polarity epochs 2 (Matuyama) to 1 (Brunhes).

Uzunlarian, Karangatian and Neoeuxinian

The Uzunlarian takes its name from a lake, the Karangatian takes its name from a promontory on the Kerch Peninsula (Crimea), and the Neoeuxinian its name from an ancient name for the Black Sea (Likharev, 1958). The Uzunlarian, Karangatian and Neoeuxinian appear equivalent to the Khazarian, Girkan and Khvalynian respectively of the Caspian (Pleistocene-Holocene). Zubakov & Borzenkova (1990) calibrate the Uzunlarian, Karangatian and Neoeuxinian against magnetostratigraphic polarity epoch 1 (Brunhes).

Details of Uzunlarian, Karangatian and Neoeuxinian stratigraphy have been discussed by Schrader (1979) and Markova & Mikhaleska (1994). Schrader (1979) recorded the palaeoenvironmentally significant diatoms *Actinocyclus divisus, A. ochotensis, Cymatopleura solea* and *Stephanodiscus astraea* (which indicate a palaeosalinity range of 0.5–3.0ppt). Markova & Mikhaleska (1994) recorded the ostracods *Amnicythere cymbula, Callistocythere alfera, C. lopalica, C. mediterrarea, C. quinquetuberculata* and *Loxoconcha immodalata* in the stratotypical Uzunlarian.

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