HP/LT metamorphism and the structure of the Alanya Massif, Southern Turkey: an allochthonous composite tectonic sheet

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SUMMARY: The southern part of the Alanya Massif is made up of three superposed, relatively flat-lying, crystalline nappes (Alanya Nappes), which tectonically overlie the largely sedimentary lithologies of the Antalya Unit (= Antalya Complex). The predominantly Mesozoic continental margin type lithologies of the Antalya Unit outcrop beneath the Alanya Nappes in a large tectonic window.

The structurally lowest of the Alanya Nappes (Mahmutlar Nappe) consists of a heterogeneous series of shales, sandstones, dolomites, limestones and quartzites all metamorphosed under greenschist facies conditions. At least part of the sequence is Permian in age. The intermediate Nappe (Sugözü Nappe) is made up of garnet-micaschists which contain bands and lenses of eclogites and blueschist metabasites. Petrographic study has shown that rocks of the Sugözü Nappe have undergone initial HP/LT metamorphism followed by greenschist facies metamorphism. The greenschist overprint has destroyed most of the primary HP/LT mineral assemblages. The structurally highest of the Alanya Nappes (Yumrudağ Nappe) consists of a thick Permian carbonate sequence underlain by a relatively thin schist unit metamorphosed under lower greenschist facies conditions.

The absence of HP/LT metamorphism in the structurally lowest and highest of the Alanya Nappes, and the greenschist facies metamorphism which has affected all three nappes indicate that the initial HP/LT metamorphism of the Sugözü Nappe was succeeded by the tectonic stacking of the Alanya Nappes, greenschist facies metamorphism and deformation. In post-Maastrichtian times the Alanya Nappes, which were by then welded into one unit, were thrust over the sedimentary rocks of the Antalya Unit. The final thrusting of the Alanya Nappes and the underlying Antalya Unit over the Tauride carbonate platform occurred before the Middle Eocene.

The Alanya Massif is the name given to a large area of metamorphic rocks situated east of Antalya Bay in the Eastern Mediterranean (Blumenthal 1951). Here we show the Alanya Massif to be an allochthonous, composite tectonic slice overlying the predominantly Mesozoic sedimentary rocks of the Antalya Unit. We also describe for the first time eclogites and blueschists in the middle of the three crystalline nappes which make up the Alanya Massif. Interestingly this discovery follows the description of abundant detrital sodic amphibole in the beach and river sediments on the southern Turkish coast (Mange-Rajetzky 1981), some of which were certainly derived from these newly discovered HP/LT metamorphic rocks.

The Mediterranean coast of Turkey is flanked by the Tauride mountain chain which consists of superposed nappes stacked together during the Upper Cretaceous and Tertiary (Brunn *et al.* 1971; Özgül & Arpat 1973; Özgül 1976). A sedimentary sequence extending from Cambrian to Eocene, with the Mesozoic represented largely by platform carbonates, forms the Tauride autochthon in the Central Taurides. Around Antalya bay the autochthon is overthrust by the rocks of the Antalya Unit (Özgül 1976, equivalent to the Antalya Nappes of Lefèvre 1967, and the Antalya Complex of Robertson & Woodcock 1979), consisting predominantly of Mesozoic rocks of continental margin affinities. East of Antalya bay between Alanya and Anamur, rocks of the Antalya Unit are in turn tectonically overlain by the metamorphic rocks of the Alanya Massif (Fig. 1). Rocks belonging to the Antalya Unit outcrop beneath the Alanya metamorphics in a large tectonic window (Özgül & Arpat 1973; Özgül 1976), and in a narrow zone between the Alanya Massif and the autochthon (Fig. 1). In the east the Alanya Massif and the Tauride autochthon are overthrust by the rocks of the Aladağ Unit (Fig. 1, Özgül 1976, equivalent to the Hadim Nappe of Blumenthal 1944), which consist of a continuous shelf-type sedimentary sequence ranging in age from Upper Devonian to Upper Cretaceous.

The geology of the coastal part of Alanya Massif

We have mapped the south-western coastal part of the Alanya Massif between Demirtaş and west of Alanya at a scale of 1:25 000. In this area three superimposed nappes (Alanya Nappes) have been differentiated within the crystalline Alanya Massif (Figs 2 and 3). The differentiation of the nappes is essentially based

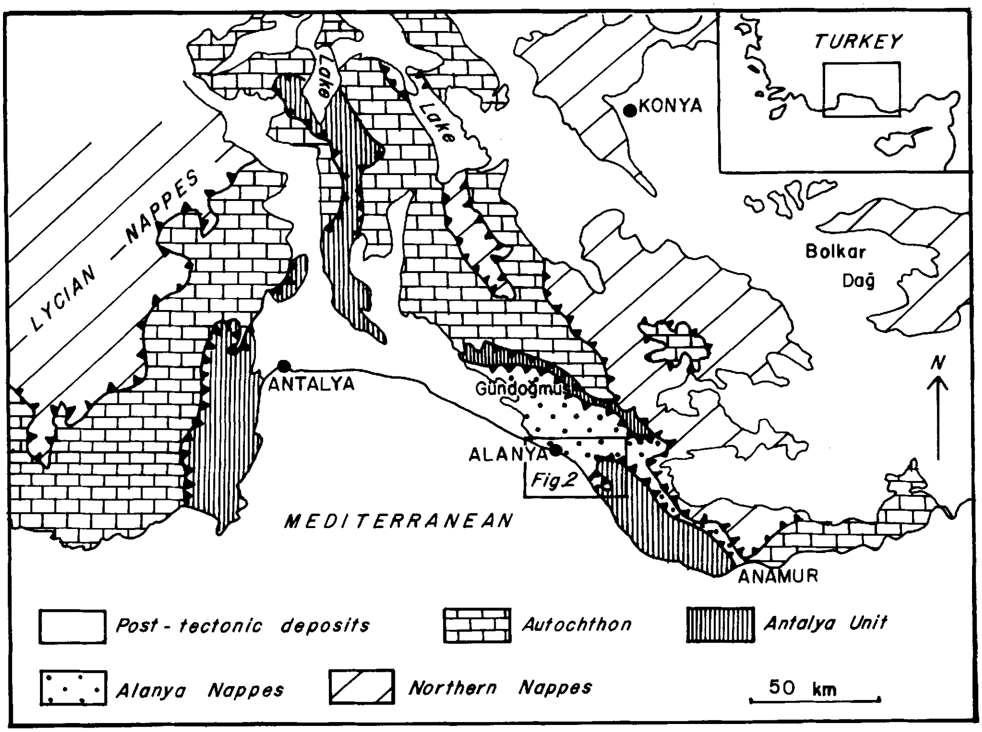

FIG. 1. Schematic tectonic map of the Western and Central Taurides showing the major tectonic units and the location of towns mentioned in the text. The location of Fig. 2 is shown by the rectangular box.

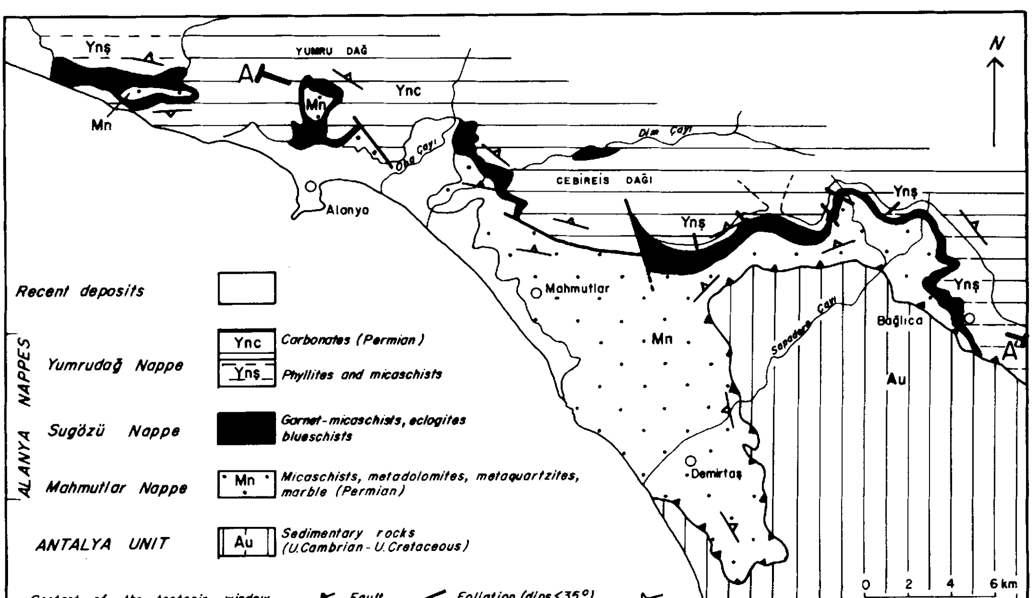

FIG. 2. Simplified tectonic map of the Alanya region showing the Alanya Nappes and part of the Alanya tectonic window.

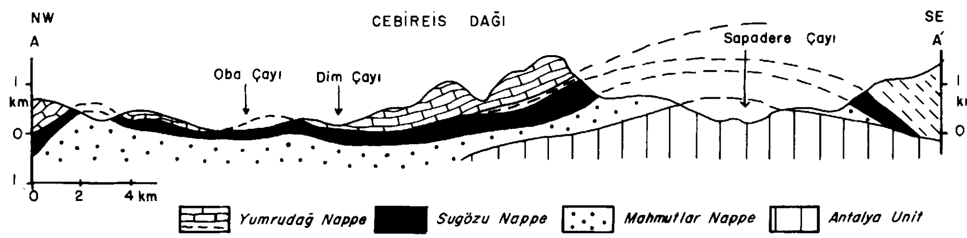

FIG. 3. Cross-section illustrating the large scale structure in the Alanya region.

on the presence of a HP/LT metamorphic slice at a structurally intermediate position in the Alanya Massif. These three Alanya Nappes tectonically overlie the predominantly sedimentary rocks belonging to the Antalya Unit, which crop out in the Alanya tectonic window.

The Alanya Nappes have a gently (<35°) undulating, but largely northerly, regional dip, such that the coastal area presents an oblique cross-section through the Alanya Nappes (Fig. 2). The formal definitions of the stratigraphy in the Alanya Nappes and especially of the Alanya tectonic window will be given elsewhere and are only summarized here.

Yumrudağ Nappe

The Yumrudağ Nappe is the structurally highest of the Alanya Nappes and constitutes the bulk of the Alanya Massif. It consists of schists overlain by a thick sequence of recrystallized limestone. The passage from the schists to the overlying carbonates is gradational with schist and carbonate bands several metres thick at the contact. Pelites, psammites, calc-schists, meta-dolomites and thin recyrstallized limestone bands are the major lithologies of the schist unit. The thickness of the schist unit is very variable; in some areas it is completely cut out and the carbonates rest directly on the garnet-mica-schists of the Sugözü Nappe. In the eastern part of the area, where the basal schist unit reaches its maximum thickness, it is 1200 m thick. The meta-clastic rocks show a well developed planar cleavage; the typical mineral assemblage in the pelites is quartz + albite + phengite + chlorite ± biotite. Some of the less well recrystallized psammites contain abundant clastic microcline.

The overlying carbonate unit forms the thick carapace of the Alanya Massif (Blumenthal 1951). Several hundred metres of generally flat-lying, grey, massively-bedded, monotonous recrystallized limestones and dolomites are the characteristic lithology. There are occasional calc-schist bands and local meta-bauxite horizons. The deceptively flat-lying structure of the carbonate unit hides strong isoclinal folding prominent in the lower levels; the real thickness of the carbonate unit must be much less than the apparent thickness (>1000 m).

Since the work of Blumenthal (1951), it is known from the well preserved *Mizzia* seen on the weathered carbonate surfaces that the carbonates are of Upper Permian age. A recently discovered exposure in the Alanya Massif shows the massive Permian carbonates to pass through a meta-bauxite horizon to thinly bedded recrystallized limestones with abundant lamellibranchs. Surprisingly similar but better preserved sequences in the Alanya tectonic window suggest that the thinly bedded limestones are Lower Triassic (Scythian) in age. Younger rocks are not found in the Yumrudağ Nappe.

Sugözü Nappe

This is a thin HP/LT metamorphic unit occupying a structurally intermediate position between the Yumrudağ Nappe above and Mahmutlar Nappe below. The dominant rock type in the Sugözü Nappe is a well-foliated, silvery-grey mica-schist with conspicuous reddish-black garnets up to 6 mm in size. These very distinctive garnet-mica-schists were also noted by Blumenthal (1951) and Peyronnet (1971). Eclogites and blueschist metabasites occur within these garnet-mica-schists either as rare intercalated bands 20–30 cm thick or as boudinaged lenses which can range up to two metres across. These basic lithologies make up less than 5% of the Sugözü Nappe. A still rarer lithology is meta-dolomite. The garnet-mica-schists were probably originally siliceous shales. Petrological studies, which are detailed in the next section, indicate that these rocks experienced a *plurifacial* metamorphism ranging from eclogite to greenschist facies.

The apparent thickness of the Sugözü Nappe ranges from 100 to 800 metres and the maximum outcrop width is about one kilometre.

Despite its relative thinness the Sugözü Nappe shows a remarkable lateral continuity. It is traceable for over 40 kilometres along the coast, beneath and south of the Yumrudağ Nappe and is cut out in only one place by a steeply dipping normal fault (Fig. 2). In the east the Sugözü Nappe is truncated by the Alanya tectonic window, whereas in the west it disappears beneath recent sediments (Fig. 2). North of the Yumrudağ Nappe it reappears in a small window in a deeply cut gorge (Dim Çayı), which gives a minimum N-S dimension of four kilometres.

Along all the observed contacts, the foliation in the garnet-mica-schists is parallel to the foliation in the overlying and underlying schists. The demarcation of the Sugözü Nappe is made in the field solely on the presence of conspicuous garnets in this unit; garnets are lacking in the Yumrudağ Nappe and in the directly underlying schists of the Mahmutlar Nappe. The conformable contacts between these three nappes, which has prevented their earlier discovery, is due to the last stage of metamorphism and deformation which affected all three nappes. However, on a larger scale there is discordance between the generally E-W trending garnet-mica-schists of the Sugözü Nappe and the NW-SE trending lithologies of the underlying Mahmutlar Nappe (Fig. 2). Near the contact, the Mahmutlar Nappe schistosity becomes concordant with that in the garnet-mica-schists of the Sugözü Nappe.

Mahmutlar Nappe

This structurally lowest of the Alanya Nappes consists predominantly of pelites, psammites, meta-dolomites, recrystallized limestones and meta-quartzites. Meta-dolerites and recrystallized radiolarian cherts occur in very minor amounts. The thickness of the Mahmutlar Nappe is difficult to estimate as its lower contact is under the sea. However, it has a minimum apparent thickness of 700–800 metres. In the east it is truncated along with the Sugözü Nappe by the Alanya tectonic window; west of Alanya it is largely covered by the overlying nappes and crops out only in small windows (Fig. 2).

The metamorphic grade in the Mahmutlar Nappe continuously increases from the north-east towards the south-west. In the north-east the clastic quartz and feldspar grains in coarse sandstones are still recognizable whereas near the coast pelites contain biotite and newly-formed small garnets along with oligoclase, quartz, phengite and chlorite. A well developed schistosity is ubiquitous in the metaclastic rocks of the Mahmutlar Nappe. The presence of *Mizzia* in some recrystallized limestones north of Demirtaş village indicates that at least part of the Mahmutlar Nappe is of Permian age.

Alanya tectonic window

Sedimentary and low-grade metasedimentary rocks belonging to the Antalya Unit outcrop in an immense tectonic window underneath the Alanya Nappes extending for 75 km along the coast from Demirtaş to Anamur (Fig. 1). Its south-western margin is under the sea whereas along its north-eastern flank the Alanya Nappes tectonically overlie the sediments of the Antalya Unit. In the north-western part of the window a thin sequence (150 m) of micaceous Upper Cambrian-Lower Ordovician sandstones and siltstones with rare, red nodular limestone intercalations is overlain by Upper Permian neritic carbonates. An orthoquartzite horizon between the Lower Palaeozoic sandstones and Permian carbonates is interpreted as the transgressive base of the Permian. The thickly bedded, grey, neritic, fossiliferous Permian limestones, 600–700 m thick, are overlain by variegated, thinly bedded Scythian limestones and marls with abundant lamellibranchs. This 200 m thick sequence passes upwards into red radiolarian cherts and intercalated Halobia-bearing pelagic limestones. In this 30 m thick pelagic sequence there are rare intercalations of green acidic tuffs and alkali basalts. The radiolarian cherts and pelagic limestones are overlain by 600 m of greyish brown, carbonaceous Carnian sandstones with abundant plant debris. A distinctive feature of these sandstones is the presence, especially in the upper levels, of olistoliths mostly of Permian limestone, Ordovician sandstone and Cambrian red nodular limestone. These olistoliths may reach several kilometres in size.

Jurassic and Cretaceous rocks occur in only few areas in the Alanya tectonic window. They are faulted against the much more abundant Triassic rocks and comprise a 150 m sequence of multicoloured radiolarian cherts and pelagic limestones. At the top of the sequence there is a Maastrichtian shale unit with olistoliths ranging in age from Cambrian to Cretaceous.

Low-angle thrusting is common within the window so that the stratigraphic sequences are repeated several times. The thrusts trend in a north-south direction and are truncated by the overlying Alanya Nappes. On a finer scale the Triassic sandstones and shales are strongly and complexly deformed. Metamorphic recrystallization and penetrative cleavage, which is lacking in the north-eastern part of the window, develops gradually towards the coast. Along

TABLE 1. *Measured modes of typical rocks from the Sugözü Nappe*

	Metabasite			Micaschist	
	AL497B	AL497A	AL426	AL431	AL512
Sodic pyroxene	62.9	26.4	—	—	—
Garnet	11.0	14.0	9.5	5.5	9.0
Sodic amphibole	3.5	34.9	10.7	0.2i	—
Barroisite	—	1.8	17.8	—	—
Albite	—	—	23.1	22.5	25.0
Chlorite	0.5	—	9.6	9.4	1.9
Ankerite	—	2.9	9.3	—	0.2
Calcite	—	—	3.2	—	—
White mica	15.0	7.9	8.9	18.8	19.2
Biotite	—	—	1.7	4.6	tr.
Quartz	0.6	2.5	1.2	36.8	43.7
Clinozoisite	0.1	0.7	0.2	tr.i	—
Magnetite	1.6	0.2	—	—	—
Pyrite	1.6	2.1	—	—	—
Pyrrhotite	—	—	0.9	—	—
Ilmenite	—	—	—	2.0	0.9
Rutile	3.2	6.2	0.1	tri.i	tri.i
Sphene	—	—	3.2	—	—
Apatite	—	0.4	0.4	0.2	0.1
Tourmaline	—	—	0.2	tr.	—
	100.0	100.0	100.0	100.0	100.0

tr. <0.1
i inclusions in garnet

the coast the shales are converted to quartz-chlorite-sericite schists with an irregular penetrative cleavage. However, the grade of metamorphism in the window is less than in the surrounding schists of the Alanya Nappes.

Petrology of HP/LT metamorphic rocks of the Sugözü Nappe

Eclogites and blueschist metabasites occur as dense, massive, dark bands or lenses within the silvery grey, well foliated garnet-mica-schists. Petrographically there is a complete and continuous range from essentially unaltered eclogite through blueschist metabasite to barroisitic amphibolite. The earliest eclogitic and blueschist stages are best preserved in the eastern part of the Sugözü Nappe, especially around the village of Bağlica (Fig. 2). West of Alanya most of the traces of the eclogitic stage are obliterated.

Unaltered *eclogites* are rare. In hand specimen 2–3 mm large reddish-black garnets are set in a yellowish-green fine-grained matrix. Under the microscope large garnet poikiloblasts lie in a sheared groundmass composed dominantly of pale green subhedral grains of sodic pyroxene. White mica, pale blue sodic amphibole with narrow rims of bluish-green barroisite, and quartz, rutile and pyrite occur in minor amounts (Table 1). Garnet crystals are full of inclusions of sodic amphibole, clinozoisite, white mica and rutile.

Blueschist metabasites are more common than eclogites. They occur as massive, hard, banded, bluish-black rocks with conspicuous reddish garnets several millimetres in size. Rotated and deformed garnet poikiloblasts up to 5 mm in diameter are set in a groundmass of sodic amphibole, sodic pyroxene and white mica. Rutile, pyrite, quartz, altered Fe-carbonate, and clinozoisite are found in smaller amounts scattered in the groundmass (Table 1). There is a graduation from omphacite + garnet eclogites to blueschist metabasites with sodic amphibole and garnet but with no sodic pyroxene. In many blueschist metabasites sodic pyroxene is preserved in patches or in bands; there are, however, no direct replacement textures of sodic pyroxene by sodic amphibole. Pale blue sodic amphibole shows ubiquitous partial replacement by greenish blue barroisite; however, in blueschist metabasites barroisite never makes up more than 30% of the amphibole present. Garnet porphyroblasts have abundant inclusions of sodic amphibole, clinozoisite, quartz, carbonate and rutile. Quartz, calcite and white mica are concentrated in the pressure shadows and around the rims of the garnet porphyroblasts.

TABLE 2. *Stages of mineral development in metabasic rocks of the Sugözü Nappe*

Mineral \ Facies	Eclogite	Blueschist	Greenschist
Garnet	———	———	———
Na-pyroxene	———	– – –	
Na-amphibole	———	———	– – –
Barroisite			———
Albite			———
Chlorite			———
Epidote	– – –	– – –	– – –
Paragonite	———	———	———
Phengite	———	———	———
Biotite			– – –
Rutile	———	—— – –	– –
Sphene		–	———
Quartz	– – –	– – –	– – –

Barroisite amphibolites represent the last stage in the retrogressive development of eclogites. They are less dense than the blueschist metabasites and eclogites, and have a pale-green colour due to the presence of abundant chlorite and albite in the rock. Red garnets are still conspicuous on weathered surfaces. These large garnet poikiloblasts are associated with sub-idioblastic barroisite, which has largely replaced the pale blue sodic amphibole, and with albite poikiloblasts, quartz, white mica and chlorite. Sphene replacing rutile, altered Fe-carbonate, clinozoisite, biotite and pyrite may occur in minor amounts (Table 1).

The mineralogy and texture of the *garnet-mica-schists* are, like their field characteristics, rather monotonous. Poikilitic, often rotated, garnet porphyroblasts up to 1 cm across are associated with helicitic albite poikiloblasts, pale green chlorite, phengite and quartz. These five minerals make up over 90% of the mode (Table 1). Small amounts of ilmenite, biotite, graphite, clinozoisite and altered Fe-carbonate may be present. Rutile (occasionally replaced by sphene), apatite and tourmaline are ubiquitous accessory minerals. The most interesting feature of the garnet-mica-schists is, however, the presence of sodic amphibole, which occurs in minor amounts along with quartz, white mica, clinozoisite and rutile as small inclusions in garnet porphyroblasts or even more rarely in large Fe-carbonate crystals.

Sodic amphibole inclusions in garnets and the interlayering of garnet-mica-schists and metabasic rocks indicate that the garnet-mica-schists have undergone an initial HP/LT metamorphism as have the basic lithologies. The initial HP/LT mineral assemblage of the garnet-mica-schists probably included jadeite instead of albite.

The evolution of mineral assemblages in the metabasic rocks is shown in Table 2. Geological evidence (cf. Table 4) indicates that HP/LT metamorphism and greenschist facies metamorphism represent two distinct events rather than a single continuous event. In this respect rocks of the Sugözü Nappe are similar to the HP/LT metamorphic rocks from the Western Alps and especially from the Sesia-Lanzo Zone (Frey *et al.* 1974). As in the Sugözü Nappe, rocks of the Sesia-Lanzo Zone are largely quartz-rich mica-schists representing metamorphosed acid magmatic rocks and pre-Alpine schists (Compagnoni *et al.* 1977). On the other hand, rocks of the Sugözü Nappe show a strong contrast in terms of the mineral assemblage, lithology and tectonic setting to the prograde blueschists of north-west Turkey, which occur 300 km north of Alanya Nappes (Okay 1982 and this volume).

Mineral chemistry

Fifty-five complete mineral microprobe analyses have been made on three samples: one eclogite (497B), one barroisite amphibolite with relict sodic amphibole (426) and one garnet-mica-schist (431). The measured modes of these specimens are given in Table 1; all three samples are kept in the Harker Collection in the Department of Earth Sciences, Cambridge.

Mineral compositions were determined for twelve elements (Na, Ca, K, Fe, Mg, Mn, V, Cr, Ti, Al, Si, P) using an electron-probe microanalyser with a Harwell Si(Li) detector and pulse processor (Statham 1976). The correction procedures are given by Sweatman & Long (1969). The method for estimating ferric ion in sodic pyroxene and in sodic amphibole is outlined in Okay (1978, 1980).

Garnet

Idioblastic garnet porphyroblasts are ubiquitous in metabasic rocks and mica-schists. Nine garnet compositions from the three samples are plotted in Fig. 4 in terms of pyrope, grossular and almandine + spessartine end-members and two of the analyses are given in Table 3. Analysed garnets have very low spessartine (<2%) and andradite (<3%) components, and show a slight zoning involving an increase in almandine component towards the rim at the expense of the grossular component. The pyrope contents range from 4% to 9%; garnets from the metabasic rocks are slightly

TABLE 3. *Representative mineral analyses*

	Garnet			Sodic pyroxene		Amphibole		Paragonite		Phengite		Epidote	Chlorite
	AL497B		AL431	AL497B		AL426		AL426	AL497B	AL426	AL431	AL497B	AL426
	core	rim											
SiO_2	37.72	38.60	38.74	57.23	56.13	57.22	50.13	46.82	46.84	48.57	51.05	39.41	27.27
Al_2O_3	21.05	21.47	21.23	14.60	12.44	11.31	10.18	38.37	38.95	27.42	27.40	29.98	20.20
TiO_2	0.17	0.00	0.17	0.00	0.00	0.00	0.20	0.00	0.13	0.33	0.29	0.00	0.00
FeO	27.26	30.56	28.26	10.06	8.87	14.06	13.62	0.68	0.72	2.57	2.83	5.98	21.59
MnO	0.48	0.28	0.91	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00
MgO	1.46	2.09	1.07	1.69	4.40	7.03	11.63	0.00	0.00	2.82	2.46	0.00	18.48
CaO	11.05	8.51	11.05	4.32	8.39	0.45	8.31	0.42	0.14	0.22	0.00	23.61	0.15
Na_2O	0.00	0.00	0.00	12.06	9.56	6.64	3.31	6.49	7.28	0.42	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.18	1.00	0.81	9.55	10.36	0.00	0.00
Total	99.69	101.51	101.93	100.07	99.79	96.71	97.56	93.78	94.87	91.90	94.39	99.17	87.69
Number of cations per													
	12 cations			4 cations		23 oxygens		22 oxygens		22 oxygens		12.50	28.0
Si	3.00	3.02	3.03	2.01	2.00	8.04	7.22	6.08	6.02	6.71	6.86	3.00	5.62
Al^4	0.00	0.00	0.00	0.00	0.00	0.00	0.78	1.92	1.98	1.29	1.14	0.00	2.38
Al^6	1.98	1.98	1.96	0.61	0.52	1.88	0.95	3.95	3.93	3.18	3.20	2.68	2.52
Ti	0.01	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.01	0.03	0.03	0.00	0.00
Fe^{3+}	0.01	0.02	0.03	0.21	0.14	0.00	1.64	0.07	0.08	0.30	0.32	0.38	3.72
Fe^{2+}	1.85	1.99	1.85	0.09	0.12	1.65						0.00	
Mn	0.03	0.02	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Mg	0.18	0.25	0.13	0.09	0.23	1.47	2.50	0.00	0.00	0.58	0.49	0.00	5.67
				1.00	1.01	5.00	5.11	4.02	4.02	4.09	4.04		
Ca	0.94	0.72	0.93	0.17	0.32	0.07	1.28	0.06	0.02	0.03	0.00	1.92	0.03
Na	0.00	0.00	0.00	0.82	0.66	1.81	0.92	1.63	1.81	0.11	0.00	0.00	0.00
K	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.17	0.13	1.68	1.78	0.00	0.00
				0.99	0.98	1.88	2.24	1.86	1.96	1.82	1.78	7.99	19.94
Alm	61.7	66.8	62.3	Jd 61	52								
Spess	1.0	0.7	2.0	Ac 21	14								
Pyr	6.0	8.4	4.4	Au 18	34								
Gross	31.3	24.1	31.3										

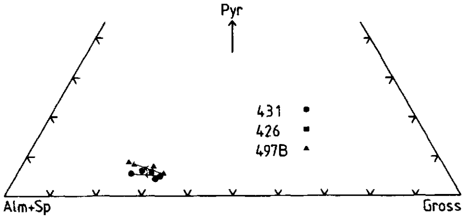

FIG. 4. Garnet compositions from the Sugözü Nappe plotted on the (almandine + spessartine)-pyrope-grossular diagram; all spessartine contents are below 2%, arrows point from core to rim compositions.

richer in pyrope component (5–9%) than garnets from the mica-schists (4–7%). Garnets from the Sugözü Nappe are similar in composition to the garnets from Type C eclogites and blueschists (Coleman *et al.* 1965).

Sodic pyroxene

Sodic pyroxenes form zoned subhedral pale yellowish-green grains or bundles of prismatic crystals up to 1 mm long. Analysed sodic pyroxenes from the specimen 497B are omphacites and aegirine-jadeites (Table 3). Their acmite contents are below 30% and their jadeite contents range up to 70%.

Amphibole

The primary amphibole is a slightly zoned colourless to pale blue sodic amphibole. Analysed amphiboles from specimen 426 plot near the ferroglaucophane/glaucophane join in the Miyashiro diagram and have very small amounts of ferric iron (Table 3, Fig. 5). They are very similar in composition to the detrital sodic amphiboles from beach sediments on the eastern part of the Alanya coast (Mange-Rajetzky 1981, Fig. 5).

In most specimens sodic amphibole has distinct and sharply bounded rims of dark bluish-green barroisite; there is no continuous compositional range between the two amphiboles. Barroisite is characterized by a small A-site occupancy (0.0–0.3 per formula unit), tetrahedral aluminium (0.6–0.9) and a Na/Na + Ca ratio of 0.3–0.5 (Fig. 5, Table 2).

Sheet silicates

Microprobe analyses have revealed that paragonite and phengite are both present in rocks of basic composition whereas only phengite is found in the garnet-mica-schists. Paragonite shows up to 12% substitution by muscovite and up to 3% by calcium mica (Table 3). Phengite coexisting with paragonite contains 6% of a paragonite component (Table 3); phengites from garnet-mica-schists on the other hand do not show any paragonite substitution.

Chlorite is largely retrogressive after garnet in garnet-mica-schists and blueschist metabasites. In barroisite amphibolites, however, it forms an important part of the primary mineral assemblage. Chlorites analysed from the barroisite amphibolite and from the garnet-mica-schist have restricted Fe/Fe + Mg ratios (0.4–0.5) and a uniform Si/Si + Al ratio (Table 3).

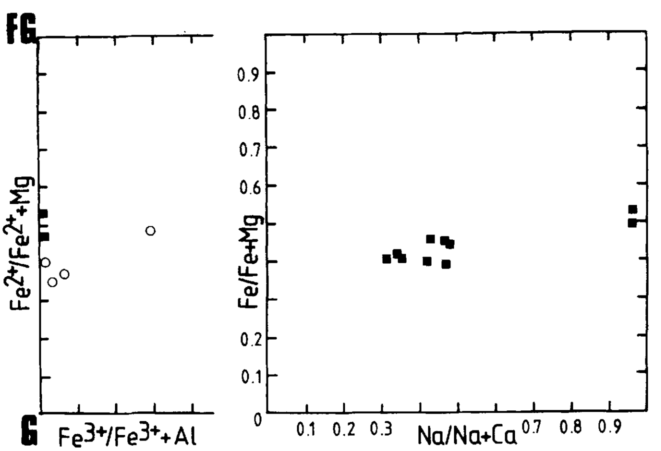

FIG. 5. Amphibole compositions from the Sugözü Nappe.
(a) Sodic amphibole compositions plotted on part of the Miyashiro diagram. Open circles indicate sodic amphibole compositions from the beach and river sediments from the eastern province, Alanya (Mange-Rajetzky 1981). G = glaucophane, FG = ferroglaucophane.
(b) Barroisite and sodic amphibole compositions from the sample AL426 plotted in terms of their Na/Na + Ca and Fe/Fe + Mg ratios. The diagram illustrates the compositional break between the sodic amphibole and barroisite.

TABLE 4. *Structural and metamorphic events in the Alanya area*

1.	Shallow carbonate platform conditions in the Alanya Nappes and Antalya Unit	Upper Permian
2.	Rifting of the carbonate platform	Anisian
3.	HP/LT metamorphism of the Sugözü Nappe	
4.	Tectonic stacking of the Alanya Nappes	
5.	Greenschist facies metamorphism of the Alanya Nappes and probably part of the Antalya Unit	pre-Maastrichtian
6.	Thrusting of the Alanya Nappes as a single sheet over the Antalya Unit	post-Maastrichtian
7.	Alanya Nappes and the underlying Antalya Unit thrust over the carbonate platform to the north	Palaeocene-Lower Eocene

Other minerals

Albite is present in barroisite amphibolites and in garnet-mica-schists. The maximum anorthite content in five analysed albites from two specimens is 3 mol %.

Epidotes, with pistacite contents of 12–17 mol % occur in minor amounts in metabasic rocks (Table 3).

Metamorphic and tectonic history of the Alanya area

The geological evolution of the Alanya area involves a complex sequence of structural and metamorphic events, which are summarised in Table 4. Petrographic and structural evidence indicates that only the Sugözü Nappe has suffered HP/LT metamorphism, whereas greenschist facies metamorphism and associated deformation have affected all three nappes.

The initial HP/LT metamorphism of the Sugözü Nappe was followed by the tectonic stacking of the Alanya Nappes, and greenschist facies metamorphism and associated deformation, which probably also resulted in the folding of the thrust surfaces of the Alanya Nappes (Fig. 2). The low-grade metamorphism of part of the Antalya Unit is also probably related to this late greenschist event. This was succeeded by the thrusting of Alanya Nappes, which were by then welded into one sheet, over the Antalya Unit. A post-Maastrichtian age for the thrusting is given by the youngest sediments of that age in the Alanya tectonic window. Similar reasoning suggests that metamorphism in the Alanya Nappes is probably pre-Maastrichtian. Metamorphosed Lower Triassic rocks of the Yumrudağ Nappe give a minimum age for the greenschist facies metamorphism. The lack of any recorded Hercynian or older metamorphism in the Taurides suggests that the metamorphism of the Alanya Nappes is Alpine in age.

In areas of similar plurifacial metamorphism, like the Western Alps or the Cyclades, Greece, an early HP/LT metamorphism was followed 20–40 Ma later by a greenschist facies metamorphism (e.g. Frey *et al.* 1974; Altherr *et al.* 1979). In the Western Alps the initial HP/LT metamorphism seems to have predated the major nappe movements. Assuming a similar pattern for the Alanya Nappes, and a Lower Maastrichtian age for the greenschist facies metamorphism, the initial HP/LT metamorphism might be Turonian in age or older.

In the north, rocks of the Antalya Unit tectonically overlie Cretaceous and Lower Eocene carbonates and clastics of the Tauride autochthon. On the other hand, Lutetian limestones are transgressive with a basal conglomerate over the Alanya Nappes in the region of Maha Yaylasi. Thus the final emplacement of the Antalya Unit and Alanya Nappes can be constrained to the Lower-Middle Eocene interval. However, emplacement had probably started in the Palaeocene as flysch-type clastics of Upper Palaeocene-Lower Eocene age in the Tauride autochthon to the north of Alanya Nappes contain abundant schist and marble fragments derived from the Alanya Nappes.

Regional implications

Lying structurally between the Tauride autochthon and the Alanya Nappes are rocks belonging to the Antalya Unit. The original place of deposition and thus the direction of tectonic transport of the Antalya Unit has been a subject of controversy. We believe that regional considerations (Robertson & Woodcock 1980; Şengör & Yilmaz 1981) and recent detailed sedimentological and structural work (e.g. Robertson & Woodcock 1981) indicate that the Mesozoic rocks of the Antalya Unit were deposited on a passive continental margin situated south of the Tauride carbonate platform as originally propounded by Dumont *et al.* (1972).

Our palaeogeographic reconstructions start from this premise.

During the Palaeozoic and the earliest Triassic, the Taurides were part of Gondwanaland. In the northern parts of Gondwanaland the Upper Permian is characterized by a far-reaching marine transgression and the establishment of shallow marine conditions over large areas with the deposition of a thick sequence of neritic limestones. At the end of the Permian part of the carbonate platform was sub-aerially exposed and subject to lateritization. Deposition in a tidal environment during the Scythian is indicated by the very widespread variegated thinly-bedded limestones. The initial rifting and continental fragmentation of the northern part of Gondwanaland began during the late Anisian and led to a horst–graben type topography (Marcoux 1978). There were narrow fault-bounded basins separted by uplifted areas. In the pelagic basins radiolarian cherts, pelagic limestones, carbonate turbidites and turbiditic sandstones were deposited. The presence of granitic rock fragments, and olistoliths of Permian limestones and Ordovician sandstones in the Triassic rocks of the Alanya tectonic window, indicate that some of the uplifted areas were subareally exposed and eroded. The structural position of the Alanya Nappes over the Antalya Unit, and the apparent absence of post-Scythian sediments in the Alanya Nappes suggest that the Yumrudağ and Mahmutlar Nappes were originally part of such an uplifted continental area separated from the major Tauride carbonate platform by a rifted pelagic basin, where rocks of the Antalya Unit were being deposited.

Although there are no ophiolitic rocks in the Alanya tectonic window, it has been suggested that during the Jurassic and Cretaceous some of these basins developed oceanic crust (e.g. Şengör and Yılmaz 1981). The well known ophiolite complexes of the Eastern Mediterranean—Troodos, Kızıldağ and Antalya ophiolites—are regarded as Late Cretaceous fragments of an oceanic basin south of the Tauride carbonate platform (Robertson & Woodcock 1980). In the Alanya region the position of this southern branch of Neotethys is not clear. At the north-western margin of the Alanya Nappes near the town of Güzelsu, there are slivers of serpentinite, spilite, chert and pelagic shales (Monod 1978). Around the town of Gündoğmuş these slivers are partly metamorphosed in the blueschist facies, and are closely associated with the rocks of Antalya Unit (Şengün *et al.* 1978, and our own observations). The presence of these poorly known ophiolitic rocks may indicate that oceanic crust was generated during the Mesozoic between an Alanya microcontinent, represented by the Mahmutlar and Yumrudağ Nappes, and the Tauride carbonate platform.

The continental basement to the Antalya Unit is not observed anywhere in the Alanya area. The Sugözü Nappe could represent part of the attenuated continental basement of the Antalya Unit, which was subducted by cover-stripping during the Cretaceous (A.M.C. Şengör, personal communication). However, it remains a perplexing question as to how rocks of the Sugözü Nappe were uplifted and then preserved as a coherent, thin metamorphic slice.

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