

A boron-bearing potassium feldspar in volcanic ash and tuffaceous rocks from Miocene lake deposits, Samos Island, Greece

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ABSTRACT

The Lower Neogene Unit (LNU) of west Samos Island, Greece, consists of volcanic ash and tuffaceous rocks, claystone, marlstone, and porcelaneous limestone. The initial fresh glass of volcanic rocks has usually transformed to authigenic K-feldspar, zeolites, opal-CT, and smectite. K-feldspar is the predominant mineral in the central part of the LNU, whereas in adjacent margins, K-feldspar occurs only in the sandy tuffs. Nowhere is the K-feldspar associated with fresh glass. Chemical, SEM, and XRD analyses show the K-feldspar to be B-bearing, with B concentrations up to 2500 ppm. Statistical treatment of chemical data demonstrates a positive correlation of B with K and Rb. This B-bearing K-feldspar seems to be analogous to K-feldspars described in saline-alkaline lake deposits associated with nonmarine evaporites.

INTRODUCTION

Authigenic K-feldspar has been reported as a diagenetic product in tuffs, sandstones, and carbonates from marine and lake environments (Hay, 1966; Kastner, 1971; Goodwin, 1973; Sheppard and Gude, 1972, 1973a, 1973b; Desborough, 1975; Starkey and Blackmon, 1979; Ali and Turner, 1982; Helvacı, 1986; Obradović and Dimitrijević, 1987), but the B-bearing variety has been reported only from saline-alkaline lake deposits of tuffaceous rocks (Sheppard and Gude, 1968, 1969, 1972, 1973a, 1973b; Lefond and Barker, 1979). The relatively high B concentrations in this K-feldspar, compared to the very low B values of K-feldspar of volcanic origin (Harder, 1974; Stamatakis, 1986), suggest a partial substitution of B for Al in the series $KAlSi_3O_8$ - $KBSi_3O_8$ in certain environments (Martin, 1971; Sheppard and Gude, 1973b). The zeolites clinoptilolite and analcime, as well as the borosilicates howlite and searlesite, and smectite are the commonest paragenetic associates of this K-feldspar (Sheppard and Gude, 1968; Hay, 1970; Surdam and Parker, 1972; Smith, 1979; Obradović and Jovanović, 1987). Usually there is a gradual diagenetic transition from unaltered fresh glass through smectite and zeolites in the moderately high saline-alkaline pore fluids to K-feldspar in the most saline-alkaline pore fluids of the lake (Sheppard and Gude, 1968).

GEOLOGIC SETTING

On Samos Island, two main Neogene basins were developed, namely the basin of Mytilinii in the east and that of Karlovassi in the west (Fig. 1). The pre-Neogene basement of both basins consists of four tectonic units containing marbles, dolomites, quartzites, phyllites, and metamorphic basic-ultrabasic rocks and a younger nappe

of diabases, peridotites, cherts, and limestones (Papanikolaou, 1979; Theodoropoulos, 1979; Mezger and Okrusch, 1985).

Neogene deposits of the Karlovassi basin start with a basal reddish-brown conglomerate overlain by the Lower Neogene Unit (LNU) of Theodoropoulos (1979). The LNU has a maximum thickness of 400 m and is subdivided into four well-recognized successions, starting from the base: (1) limestones and marly limestones with scant occurrences of thin lignitic horizons, (2) tuffaceous rocks and volcanic ash layers containing abundant authigenic silicates, (3) dolomitic clays with local occurrences of evaporites, and (4) porcelaneous limestones and porcelanites rich in silica polymorphs (Stamatakis, 1986). A 200-m-thick red and green conglomerate overlies the LNU and is interbedded with Pontian-age silts and sands (Theodoropoulos, 1979). Pliocene fresh water marlstones and limestones up to 120 m thick occur at the top of the Neogene sedimentary rocks. Deposits of the basin are presumed to be continental, Tortonian through Pliocene in age (Büttner and Kovalczyk, 1978; Besenecker and Büttner, 1978; Dermitzakis and Papanikolaou, 1981). At the margins of the Karlovassi basin there are occurrences of rhyolites, dacites, trachytes, and basalts of Neogene age (Karageorgiou, 1946; Theodoropoulos, 1979). These volcanic rocks are responsible for local silicification and kaolinitization of the surrounding LNU rocks.

Samples were taken from surface exposures and from cores of three boreholes as much as 250 m deep, drilled by the Institute of Geological and Mining Research of Greece (Fig. 2).

ANALYTICAL TECHNIQUES

Samples were analyzed for B using atomic-absorption spectroscopy and a colorimetric method (Stanton and McDonald,

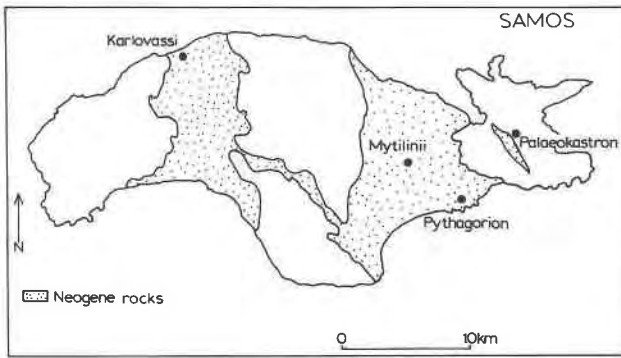


Fig. 1. The Neogene basins of Samos Island.

1966) slightly modified by Stamatakis (1986) at the Department of Geology, Athens University. Major and trace elements (Table 1) were analyzed by the plasma (ICP) method at Imperial College, London. The SEM analysis was carried out using a Cambridge S4-10 scanning electron microscope at the University of New Brunswick, Canada. The 2 μm fraction was separated by differential precipitation. A 1N HCl solution was used for the decomposition of carbonates and a Philips PW1010 X-ray diffractometer at the Department of Geology at Athens University was used for mineral analysis (Table 2). The correlation coefficient of B with certain trace and major elements was used for statistical analysis (Table 1).

PETROLOGY AND MINERALOGY OF K-FELDSPAR-RICH TUFFACEOUS ROCKS

The marginal areas of the LNU are occupied by carbonate rocks, representing an older Miocene succession above the basal conglomerate. Authigenic silicates are absent in these rocks. In contrast, all three overlying successions contain authigenic silicates and silica polymorphs. Especially in the "b" succession, which mainly occupies the central part of the Karlovassi basin, authigenic K-feldspar commonly represents more than 30 wt% of the rocks. In many cases, the 2- μm fraction is composed only of K-feldspar (Table 2). The K-feldspar is usually accompanied by clinoptilolite and/or analcime, anorthoclase, or high sanidine, illite and/or muscovite, and smectite. The following minerals are detected rarely: opal-CT, erionite, chabazite, phillipsite, biotite, chlorite, and albite (Stamatakis, 1986, Table 90). The limits of K-feldspar-rich tuffaceous rocks are defined by those rocks having a higher percentage by weight of zeolites than of K-feldspar, as determined by bulk averages of authigenic silicate occurrences (Fig. 3). This spatial development of authigenic silicates in the Karlovassi basin is analogous to zoning observed in certain saline-alkaline lake deposits (Sheppard and Gude, 1968, 1969, 1973a; Hay, 1977). The color of tuffaceous rocks varies from yellowish brown to green and dull white. In some cases turbiditic layers occur having a uniform mineral composition.

The mean particle size of these K-feldspar-rich rocks is very small, and so they might be termed volcanic ash. In the rare coarse-grained samples, transparent, prismatic

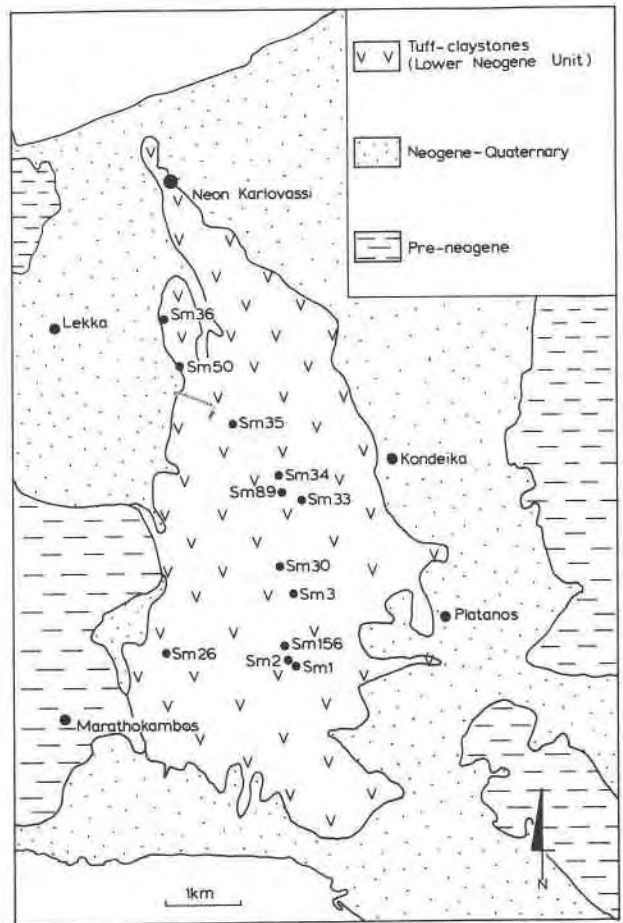


Fig. 2. Modified geologic map of the basin with sampling sites. Sm1, Sm2, Sm3 are the sites of the three boreholes.

crystals of high sanidine or anorthoclase, up to 0.5 cm in length, are observed along with well-rounded fragments of massive tuffaceous material.

Aggregates of K-feldspar were identified by XRD, SEM, and chemical analyses (Fig. 4, Tables 1, 2). Crystals of K-feldspar rarely surpass 10 μm in length and usually have an idiomorphic tabular or rhombohedral form (Fig. 4). The XRD pattern of this K-feldspar has the same intensities and d values as those described from saline-alkaline lake deposits of the western USA (Sheppard and Gude, 1965, 1973a, 1973b). The SEM microanalyses and morphological observations of the authigenic crystals of the LNU do not indicate the presence of searlesite or howlite, borosilicate minerals usually present in B-rich saline-alkaline lake deposits (Sheppard and Gude, 1968; Lefond and Barker, 1979; Smith, 1979; Smith et al., 1983; Obradović and Jovanović, 1987).

GEOCHEMISTRY AND DIAGENETIC REACTIONS

A general characteristic of the tuffaceous rocks of the LNU is their high B contents. Material notably rich in K-feldspar has B contents ranging from 1500 to 2500 ppm (Table 1). Sheppard and Gude (1972, 1973b) re-

TABLE 1. Chemical analyses of samples rich in authigenic K-feldspar

Sample	B	K	Na	Li	Rb	Mg	Ca	Sr	Ba	Al	La	Ti	Mn	Fe	Zn	Pb
Sm1:15*	1595	74000	52000													
Sm156†	1200	70000	52000													
Sm33i	840	47000	10500	84	280	11200	11700	59	98	71000	107	1890	320	1720	73	109
Sm33h	800	47000	3300	28	240	11100	18800	56	24	57000	106	1370	144	16000	42	96
Sm3:130	1320	70000	6200	123	420	11500	18800	59	40	68000	88	1550	490	17200	36	67
Sm33i*	1770	75000	5200													
Sm33h*	1760	75000	5200													
Sm33g*	2380	79000	5200													
Sm36r*	1595	75000	8900													
Sm156†	1807	77000	5100													
Sm34†	2464	85000	6300													
Sm34**†	2486	85000	5300													
Sm33a*	2365	81000	5200													
Sm36o*	2050	80000	5100													
Sm1:15a	900	62000	7100	77	340	4900	4200	48	37	72000	92	1370	380	19500	99	79
Sm1:15	820	45000	6000	340	330	16800	7100	102	42	78000	117	1400	149	17900	77	91
Sm36o	1050	65000	10900	172	430	11600	3900	96	77	73000	92	1710	1360	26000	63	65
Sm34a	870	52000	6700	105	320	13900	15800	105	80	74000	94	2100	670	15900	84	64
Sm34†	910	59000	9100	87	300	12220	14700	171	58	77000	98	1610	350	14900	76	84
Sm34a*	2535	90000	5300													
Sm33b*	2480	89000	5200													
Sm36j	856	52000	13500	104	290	14100	2400	42	63	75000	89	1770	82	13700	72	60
Sm34e*	1812	79000	5300													
Sm35*	1760	77000	11600													
Sm33b	1460	72000	4900	25	490	7300	9800	44	40	74000	95	1470	360	16200	78	71
Sm35**	1038	71000	13500													
Sm50j	1405	67000	5500	84	350	5700	2600	50	80	75000	97	1940	320	16500	72	75
Sm1:51*	1375	72000	5900													
Sm1:52*	2250	83000	12900													
Sm33*	1243	70000	5100													
Sm156†	1341	69000	5000	163	540	6900	5300	530	50	75000	135	1200	42	16900	64	69
Sm89	835	49000	5500	240	420	10000	8700	1530	42	74000	161	1080	46	17900	49	107
Sm30b	868	50000	5700	114	430	8000	12500	3900	67	76000	134	1110	96	18600	83	88
Sm26h	824	49000	4400	181	260	12200	6800	86	72	76000	101	1620	240	22000	65	75

Note: In all the samples, the values of additional trace elements are lower than the amounts given here (ppm): Cd 1.26, Ag 4.4, Cu 15, Co 13, Ni 33, Be 16, Cr 26, V 33, Mo 16, P 360. Sm1:15 means borehole no. 1, depth 15 m. Sm34a, Sm34b, Sm34c, etc. are samples of the same surface section at various stratigraphic levels. Correlation coefficients between B and the following trace and major elements: K 0.92, Na -0.09, Li -0.27, Rb 0.67, Mg -0.53, Ca -0.14, Sr -0.019, Ba -0.09, Al -0.07, La -0.19, Ti 0.05, Mn 0.14, Fe 0.17, Zn -0.28, Pb -0.47.

* Samples treated with 1N or 6N in their 2 μ m fraction.

† SmX* or SmX** are samples of the same tuffaceous layer at distances of 0.5 and 1.0 m, respectively.

ferred to B contents between 500 and 5000 ppm, but usually greater than 1000 ppm, in K-feldspars deposited in a saline-alkaline lake environment. In contrast, B contents in tuffaceous rocks of the LNU containing abundant volcanic or detrital anorthoclase and high sanidine (as opposed to authigenic K-feldspar) are less than 100 ppm, and the separated anorthoclase and high sanidine crystals have B contents of 30 and 10 ppm, respectively (Stamatakis, 1986, Table 85). Also, samples of the LNU with abundant clay minerals have B contents lower than 280 ppm (Stamatakis, 1986, Table 86), suggesting that the high B contents of the tuffaceous rocks of the LNU cannot be attributed to the presence of illite, the most B-rich clay mineral (Harder, 1974). Treatment of samples with 1N and 6N HCl indicates that the B is held in a form having low solubility. Statistical treatment of the chemical data showed that a statistically significant correlation exists between B and K and between B and Rb, indicating that B is associated with authigenic K-feldspar (Tables 1 and 2). The lack of significant correlation between B and Na, Ca, Sr, and Mg also indicates the lack of discrete Na, Sr, Ca, Mg borate minerals, and also howlite and searlesite, that would otherwise contribute substantial B concentra-

tions to the samples. The moderately high values of Sr and La in the samples are characteristic of tuffaceous rocks accompanied by evaporites in saline-alkaline lake deposits (Sheppard and Gude, 1969, 1973a; Helvacı and Firman, 1976; Helvacı, 1978, 1984, 1986).

The association of K-feldspar (KAlSi_3O_8) with clinoptilolite ($(\text{K},\text{Na})\text{AlSi}_5\text{O}_{12} \cdot 3.5\text{H}_2\text{O}$) or analcime ($\text{NaAlSi}_2\text{O}_6 \cdot \text{H}_2\text{O}$) suggests that the K^+/Na^+ , Al^{3+} , and H_2O activities have not been constant. The predominance of K-feldspar in some areas of a lake deposit indicates higher K^+/Na^+ activities than in areas containing only analcime (Smith, 1979). The activities of K^+ , Na^+ , Al^{3+} , and H_2O apparently were those required for K-feldspar-analcime-clinoptilolite stability (Fig. 5) but not for searlesite, as presumed from its absence.

GENESIS OF THE B-BEARING K FELDSPAR

Three lines of field and geochemical evidence define the environment of K-feldspar formation: the zoning of authigenic silicates, their high B contents, and the development of evaporite minerals. These parameters are characteristic of saline-alkaline deposits, where B enters the structure of authigenic silicates during diagenetic re-

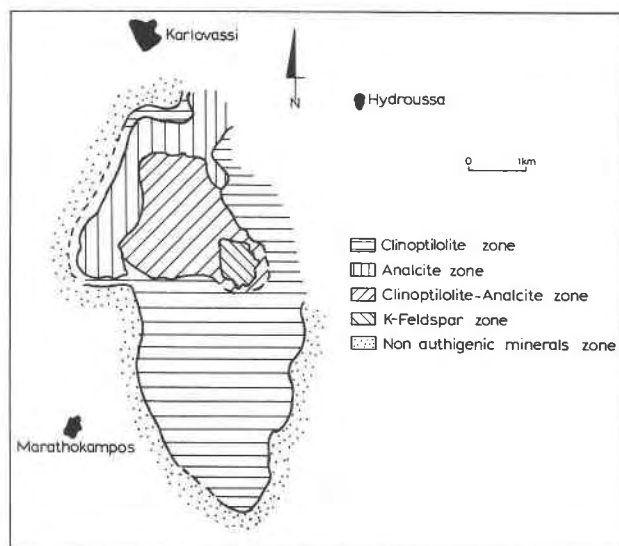


Fig. 3. Zoning of authigenic silicates in the Karlovassi basin, LNU formation. The open area in the east is covered by younger sediments.

actions involving volcanic ashes and tuffaceous rocks (Martin, 1971; Sheppard and Gude, 1973a). In general, borate ions remain in pore fluids and enter the structure of K-feldspar in the late stages of diagenesis (Sheppard and Gude, 1972). If higher B concentrations exist, then Ca, Sr, Na, and Mg borates can be formed along with K-feldspar, howlite, and searlesite.

It is well known that with an increase of salinity and alkalinity of the pore fluids, fresh glass is progressively altered according to the sequence glass → smectite → clinoptilolite → analcime → K-feldspar (Surdam and Parker, 1972; Hay, 1977). The abundance of K-feldspar in the Miocene lake, with no associated volcanic glass relicts and with its spatial relationship to adjacent zeolites, strongly suggests K-feldspar formation after other silicates in sites of higher salinity and alkalinity (Sheppard and Gude, 1973b). Its restricted occurrences at some sites in the distal part of the "b" succession, where sandy tuffaceous rocks were developed between massive clinoptilolite-rich tuffaceous rocks indicate a later stage of K-feldspar formation in areas of high porosity. The development of different diagenetic stages in the generation of authigenic K-feldspar has been observed in various lake basin deposits (Sheppard and Gude, 1972, 1973b). The types of authigenic minerals found in the Samos Miocene lacustrine deposits—principally K- and Na-bearing zeolites, K-feldspar, and Ca-, Sr-, and Na-bearing sulfate evaporites (Stamatakis, 1986)—permit the interpretation that the Miocene lake waters and pore fluids were enriched in borate, sulfate, and silicate anions and in K, Na, Ca, and Sr cations. Nonetheless, H_2O activity was relatively low in the central part of this lacustrine system, where K-feldspar predominates over the hydrous zeolites. This low H_2O activity must be attributed to the

TABLE 2. Mineral content of samples taken from volcanic ash and tuffaceous rocks

Sample	Mineral content
Sm1:15*	K-feldspar (MJ)
Sm156'	K-feldspar (MJ), anorthoclase (MD), clinoptilolite (MD)
Sm33i	K-feldspar (MJ), anorthoclase (MJ), smectite (TR)
Sm33hh	K-feldspar (MJ), opal-CT (MD), anorthoclase (MD)
Sm3:130	K-feldspar (MJ), dolomite (MD), anorthoclase (MD), smectite (TR)
Sm33i*	K-feldspar (MJ), smectite (TR), anorthoclase (TR)
Sm33h*	K-feldspar (MJ), opal-CT (MD)
Sm33g*	K-feldspar (MJ)
Sm36r*	K-feldspar (MJ), anorthoclase (TR)
Sm156*	K-feldspar (MJ), clinoptilolite (MD)
Sm34*	K-feldspar (MJ)
Sm34**	K-feldspar (MJ)
Sm33a*	K-feldspar (MJ)
Sm36o*	K-feldspar (MJ)
Sm1:15a	K-feldspar (MJ), anorthoclase (MD), muscovite (TR)
Sm1:15	K-feldspar (MJ), anorthoclase (MD), muscovite (TR)
Sm26h	K-feldspar (MJ), clinoptilolite (MJ), anorthoclase (MD)
Sm36o	K-feldspar (MJ), anorthoclase (MJ)
Sm34a	K-feldspar (MJ), anorthoclase (MJ)
Sm34	K-feldspar (MJ), anorthoclase (MJ)
Sm34a*	K-feldspar (MJ)
Sm33b*	K-feldspar (MJ)
Sm36j	K-feldspar (MJ), anorthoclase (MJ)
Sm34e*	K-feldspar (MJ), illite (TR)
Sm35*	K-feldspar (MJ), analcite (TR)
Sm33b	K-feldspar (MJ), anorthoclase (MD)
Sm35**	K-feldspar (MJ), anorthoclase (MD)
Sm50j	K-feldspar (MJ), high sanidine (MD)
Sm1:51*	K-feldspar (MJ), chabazite (TR), erionite (TR), illite (TR)
Sm1:52*	K-feldspar (MJ), chlorite (TR)
Sm33*	K-feldspar (MJ), clinoptilolite (TR), illite (TR), anorthoclase (TR)
Sm156	K-feldspar (MJ), anorthoclase (MD), clinoptilolite (MD)
Sm89	K-feldspar (MJ), anorthoclase (MD), clinoptilolite (MD), smectite (TR), illite (TR)
Sm30b	K-feldspar (MJ), anorthoclase (MD), clinoptilolite (MD)

Note: MJ, major; MD, medium; TR, trace. See also notes in Table 1.

highly concentrated solutions in the central part of the Miocene lake.

Sources for these ions were probably the volcanoclastic sediments which compose the ash falls and tuffaceous deposits of the LNU rocks. Devitrification reactions would have released these various ions into solution during diagenesis. The gradual desiccation of the late Miocene Karlovassi basin, probably attributable to the Messinian salinity crisis of the Mediterranean Sea, was responsible for the decrease of water volume and the relative enrichment of total dissolved salts in the lake. The gradual desiccation of the late Miocene basin is closely related to events postulated to have taken place in both the Karlovassi and Mytilinii basins of Samos Island (Stamatakis and Zagourogrou, 1984; Stamatakis, 1986). As a result, in the Karlovassi basin, solutions rich in B and K may have altered pre-existing zeolites to B-bearing K-feldspar. This alteration probably took place in the latest stage of lake evolution in a highly saline-alkaline environment.

POSSIBLE ECONOMIC VALUE

Aside from its uses as raw material in certain industries, K-feldspar could be used as an indicator mineral in

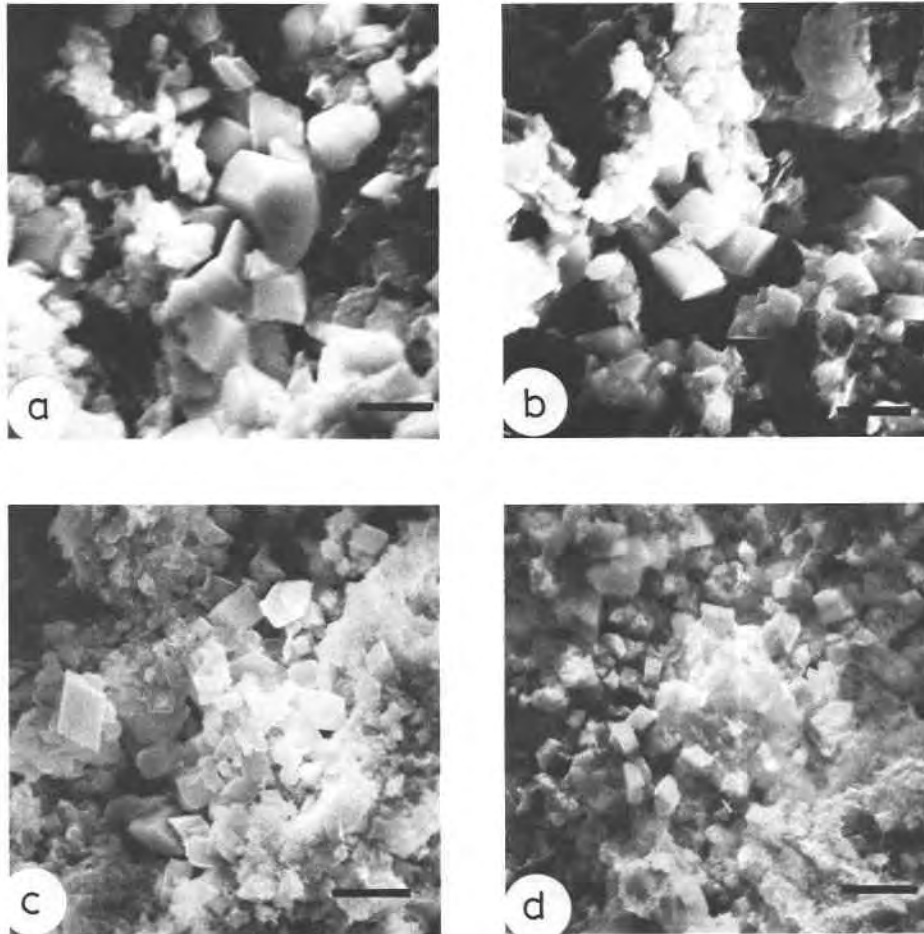
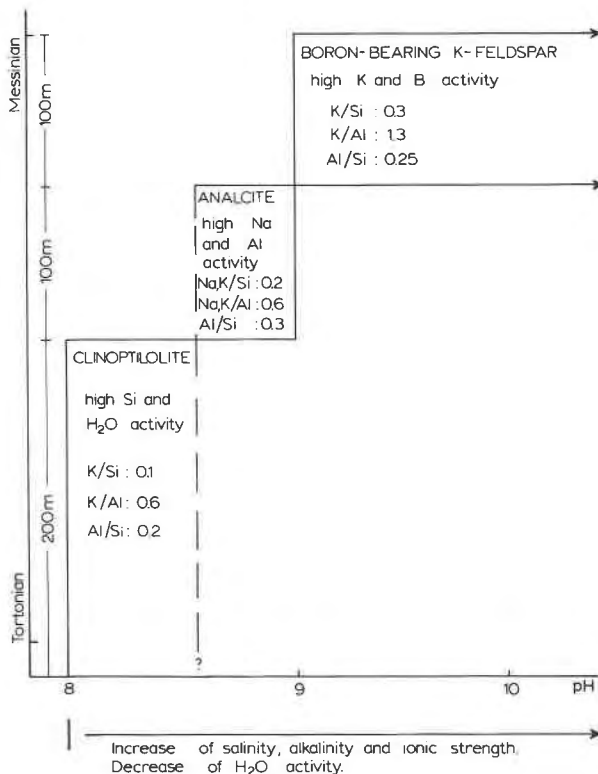


Fig. 4. SEM photomicrographs of authigenic K-feldspar from the Karlovassi basin. Idiomorphic, tabular, and rhombohedral crystals are observed. Scale bars represent 4 μm on (a), (b), and (c) and 10 μm on (d).



prospecting for evaporite minerals, as it has a genetic association with sulfates, borates, soluble carbonates, and chlorides (Sheppard and Gude, 1972, 1973b; Smith et al., 1983). The K-feldspar of the Karlovassi basin displays a close spatial relationship to the gypsum, celestite, and scant thenardite found in surface exposures of the LNU (Stamatakis, 1986). It is possible that there exists a further association of B-rich K-feldspar with other evaporites, notably borates in buried saline layers, especially those in lithostratigraphic correlation with the adjacent west Anatolian borate deposits (Helvacı, 1986).

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Fig. 5. The evolution of authigenic silicates in the Karlovassi basin.

REFERENCES CITED

- Ali, A., and Turner, P. (1982) Authigenic K-feldspar in the Bromsgrove Sandstone Formation (Triassic) of central England. *Journal of Sedimentary Petrology*, 51, 187-198.
- Besenecker, H., and Büttner, D. (1978) Late Cenozoic sediments on the islands between Euboea and Turkey. In H. Closs, D. Roeder, and K. Schmidt, Eds., *Alps, Appenines, and Hellenides*, p. 502-506. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.
- Büttner, D., and Kovalczyk, G. (1978) Late Cenozoic stratigraphy and palaeogeography of Greece. A review. In H. Closs, D. Roeder, and K. Schmidt, Eds., *Alps, Appenines and Hellenides*, p. 494-501. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.
- Dermitzakis, M., and Papanikolaou, D. (1981) Paleogeography and geodynamics of the Aegean Region during the Neogene. *Annales Geologiques des Pays Helleniques, VIIth International Congress on Mediterranean Neogene*, Athens, 1979, 1, 245-288.
- Desborough, G.A. (1975) Authigenic albite and potassium feldspar in the Green River Formation. *American Mineralogist*, 60, 235-239.
- Goodwin, J. (1973) Analcime and K-feldspar in tuffs of the Green River Formation, Wyoming. *American Mineralogist*, 58, 93-105.
- Harder, H. (1974) Boron. In K.H. Wedepohl, Ed., *Handbook of geochemistry*. Springer-Verlag, Berlin.
- Hay, L.R. (1966) Zeolites and zeolitic reactions in sedimentary rocks. *Geological Society of America Special Paper* 85, 130 p.
- (1970) Silicate reactions in three lithofacies of a semi-arid basin, Olduvai Gorge, Tanzania. *Mineralogical Society of America Special Paper* 3, 237-255.
- (1977) Geology of zeolites in sedimentary rocks. In F.A. Mump-ton, Ed., *Mineralogy and geology of natural zeolites*. Mineralogical Society of America Short Course Notes, 4, 53-64.
- Helvacı, C. (1978) A review of the mineralogy of the Turkish borate deposits. *Mercian Geology*, 6, 257-270.
- (1984) Occurrence of rare borate minerals veatchite-A, tunellite, terrugite, and cannite in the Emet borate deposits. *Mineralium Deposita*, 19, 217-226.
- (1986) Stratigraphic and structural evolution of the Emet borate deposits, western Anatolia, Turkey. *Research Papers No. MM/JEO-86, AR 008*, Dokuz Eylül University, Faculty of Engineering and Architecture, Izmir, Turkey, 28 p.
- Helvacı, C., and Firman, R. (1976) Geological setting and mineralogy of Emet borate deposits, Turkey. *Transactions of the Institution of Mining and Metallurgy, Section B, Applied Earth Sciences*, 85B, 142-152.
- Karageorgiou (1946) Volcanic rocks of Platanos area, Samos Island, Greece. *Archives of Samos*, 1, 241-286.
- Kastner, M. (1971) Authigenic feldspars in carbonate rocks. *American Mineralogist*, 56, 1403-1442.
- Lefond, S., and Barker, J. (1979) A borate and zeolite occurrence near Magdalena, Sonora, Mexico. *Economic Geology*, 74, 1883-1889.
- Martin, R. (1971) Disordered authigenic feldspars of the series $KAlSi_3O_8$ - $KBSi_3O_8$ from southern California. *American Mineralogist*, 56, 281-291.
- Mezger, K., and Okrusch, M. (1985) Metamorphism of the variegated sequence at Kallithea, Samos, Greece. *Tschermaks Mineralogische und Petrographische Mitteilungen*, 34, 67-82.
- Obradović, J., and Dimitrijević, R. (1987) Clinoptilolized tuffs from Zlatkop, near Vranje, Serbia. *Bulletin-Academie Serbe des Sciences et des Artes, Classe des Sciences Naturelles et Mathematiques: Sciences Naturelles*, Belgrade, 51, 7-19.
- Obradović, J., and Jovanović, O. (1987) Some characteristics of the sedimentation in Neogene Valjevo-Mionica lake basin (Serbia). *Bulletin Académie Serbe des Sciences et des Artes, Classe des Sciences Naturelles et Mathématiques: Sciences Naturelles*, Belgrade, 51, 53-63.
- Papanikolaou, D. (1979) Unites tectoniques and phases de deformation dans l'île de Samos, Mer Egee, Greece. *Bulletin de la Société Géologique de France*, 21, 745-752.
- Sheppard, R., and Gude, A. (1965) Potash feldspar of possible economic value in the Barstow Formation, San Bernardino County, California. *U.S. Geological Survey Circular* 500, 7 p.
- (1968) Distribution and genesis of authigenic silicate minerals in tuffs of Pleistocene Lake Tecopa, Inyo County, California. *U.S. Geological Survey Professional Paper* 587, 38 p.
- (1969) Diagenesis of tuffs in the Barstow Formation, Mud Hills, San Bernardino, California. *U.S. Geological Survey Professional Paper* 634, 35 p.
- (1972) Boron in authigenic silicate minerals of closed basin deposits. *Geological Society of America Abstracts with Programs*, 4, 410.
- (1973a) Zeolites and associated authigenic silicate minerals in tuffaceous rocks of the Big Sandy Formation, Mohave County, Arizona. *U.S. Geological Survey Professional Paper* 830, 36 p.
- (1973b) Boron-bearing potassium feldspar of authigenic origin in closed-basin deposits. *U.S. Geological Survey Journal of Research*, 1, 377-382.
- Smith, G. (1979) Subsurface stratigraphy and geochemistry of Late Quaternary evaporites, Searles Lake, California. *U.S. Geological Survey Professional Paper* 1043, 130 p.
- Smith, G., Barczak, V., Multon, G., and Liddicoat, J. (1983) Core KM-3, a surface to bedrock record of Late Cenozoic sedimentation in Searles Valley, California. *U.S. Geological Survey Professional Paper* 1256, 24 p.
- Stamatakis, M.G. (1986) Boron distribution in hot springs, volcanic emanations, marine evaporites and in volcanic and sedimentary rocks of Cenozoic age in Greece. Ph. D. thesis, University of Athens, Athens, Greece.
- Stamatakis, M.G., and Zagourogrou, K. (1984) On the occurrence of niter, Samos Island, Greece. *Mineral Wealth*, no. 33, 17-20.
- Stanton, E., and McDonald, J. (1966) The colorimetric determination of boron in soils, sediments, and rocks with methylene blue. *Analyst*, 91, 775-778.
- Starkey, H., and Blackmon, P. (1979) Clay mineralogy of Pleistocene Lake Tecopa, Inyo County, California. *U.S. Geological Survey Professional Paper* 1061, 34 p.
- Surdam, R., and Parker, B. (1972) Authigenic aluminosilicate minerals in the tuffaceous rocks of the Green River Formation, Wyoming. *Geological Society of America Bulletin*, 83, 689-700.
- Theodoropoulos, D. (1979) Geological map of Greece 1:50,000 Sheet Neon Karlovassi, IGMR, Athens, Greece.

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