Varying depositional environments of gypsum successions in the Upper Miocene Eskiehir-Sivrihisar lacustrine basin, NW Türkiye

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Varying depositional environments of gypsum successions in the Upper Miocene Eskişehir-Sivrihisar lacustrine basin, NW Türkiye

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With 7 figures and 1 table

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Abstract: The basement rocks of Eskişehir-Sivrihisar basin are made of Upper Paleozoic metamorphic rocks and Upper Cretaceous ophiolite complex. These rocks are overlain by Middle Miocene sedimentary rocks the base. Upper Miocene–Pliocene stratigraphic succession consists of basal conglomerates, sandstones, claystones, limestones, dolomites and tuffs are thinly interbedded with cyclic evaporites. The main clay mineral assemblage consists of smectite, illite and sepiolite that are enriched in different percentage in different horizons. The Upper Miocene–Pliocene stratigraphic succession consists of alterations of gypsum, clayey carbonates and unconsolidated very soft dolomite beds, which are conformably underlain by sepiolite-bearing clayey carbonates and disconformably overlain by alluvium and conglomerate series of Pleistocene age.

The Upper Miocene unit includes three different facies, based on sedimentary properties of gypsum from the base to the top; (1) laminated gypsum beds are thinly interbedded with dolomites and green clays; (2) gypsum rosettes within thin reddish and greenish clays and carbonates; and (3) scattered gypsum mainly within carbonates. Gypsums had been deposited in somewhat different depositional conditions in the same basin where multi-periodic evaporative episodes, ranging from saline to schizohaline environments, had been involved. During these episodes, under high Eh–pH intervals and high salinity conditions, three different types of gypsum formations had been developed in a meromictic-type lake under the influence of varying paleoclimatologic conditions and pore water chemistry of brines. All these gypsum morphologies respectively reflect the different conditions of environments of deposition in a Miocene playa lake basin: (1) subaqueous environments in playa lakes with short evaporation episodes; (2) marginal swamps with cyclic fluctuation

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of lake level; and (3) extended closed-lake with evaporatic lake water. These different gypsum morphologies are associated with distinctive sedimentary subfacies, which are also primarily related to cyclic climatic changes, alternating semi-arid and evaporite conditions, fluctuation of lake water level and sulphate input in the chemistry of lake water from runoff and hydrothermal source adjacent to basin.

Key words: Gypsum, Facies, Geochemistry, Lacustrine, Evaporitic Cycles, Miocene, Sepiolite.

Introduction

Sabkha is an Arabic word for a flat, salt-encrusted desert. A coastal sabkha is a broad, salt-encrusted, supratidal surface or coastal flat that is inundated only occasionally (SHEARMAN 1978). Sabkhas (interior continental and sea marginal) are equilibrium deflation-sedimentation surfaces or "deflation-sedimentation windows" through to the local water table (KINSMAN 1969). The capillary fringe above the water table marks the base of possible wind deflation. Sediment above this capillary fringe is commonly removed by the wind hence a flat surface is formed that is related to the groundwater table (FRIEDMAN 1978). Sabkha evaporites occur as part of a laterally prograding, shoaling-upward, tidal sequence in which the supertidal unit is usually no more than 1m thick and sabkha sequences are matrix dominated (WARREN & KENDALL 1985). The word playa is Spanish, and means a shore, strand, or bank of a body of water. It is commonly used for a dry bed of a playa lake. Playas are broad, shallow depressions in desert regions that occasionally may be covered with a thin sheet of water (FRIEDMAN 1978). Playa lakes are formed in closed basin, lack of external drainage, where water removes from a playa by mostly evaporation and minor by deflation or by subsurface flow. However, subsurface flow is negligible because the floors of playas are impermeable due to covering of clay-rich sediments. In continental playas the hydrological regime, which formed the playa gypsum sediments is inferred to be similar to the hydrology now forming the upper portion of a coastal saline gypsarenite unit. Gypsum is the usual surface expression of an underlying playa gypsarenite unit in Late Quaternary salt lakes in South Australia (WARREN 1982).

Sedimentology and facies analyses of the Miocene–Pliocene gypsum-bearing Kirmir Formation in lacustrine Beypazarı basin, Central Anatolia, adjacent to the Eskişehir-Sivrihisar lacustrine basin, have been studied and

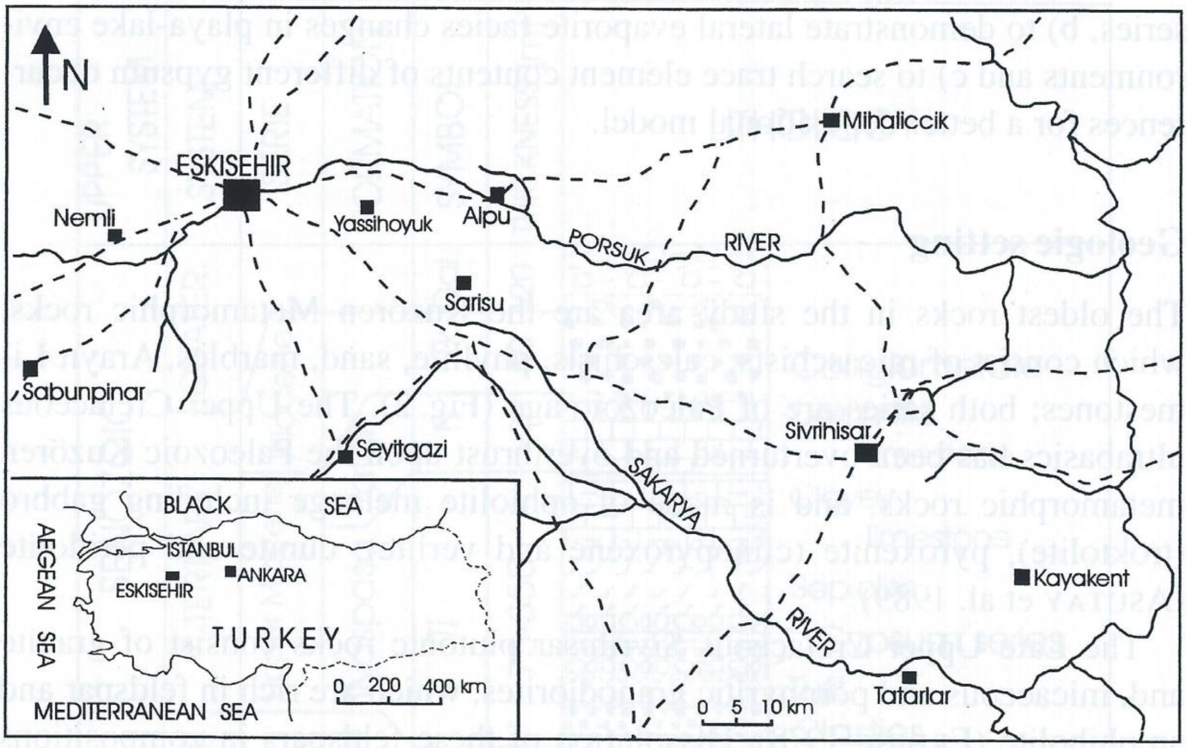

Fig. 1. Location map of the study area.

suggested that evaporite sequences were deposited in a playa-lake type environment (İNCI 1991, KARADENIZLI 1995, YAĞMURLU & HELVACI 1994).

The study area is famous because of containing world's second largest bedded and nodule type sepiolite deposits and located in the 100 km southeast of the province of Eskişehir (Fig. 1). The region is a part of the lacustrine Eskişehir-Sivrihisar Miocene basin and the upper part of stratigraphic succession, where playa lake conditions were exist during the closure episode of the Miocene lake, is the subject of this paper. The detailed geologic features of the basin have been reported by ERDINÇ (1978), KULAKSIZ (1981), GÖZLER et al. (1986), ECE & ÇOBAN (1994). Bedded nodule types sepiolite occurrences observed in the basin and were described by AKINCI (1967), YENIYOL (1986), ECE & ÇOBAN (1994), and ECE (1998). The genesis of the gypsums was discussed previously by ÇOBAN & SUNER (1993), SUNER & ÇOBAN (1995) and BELLANCA et al. (1993), concluded that stable isotopic data from dolomite samples ($\delta^{18}0 = -6$ to $+4$ %° and $\delta^{13}C = -4$ to $+0.5$ %°) indicate the existence of cyclic high evaporatic episodes.

In this study, the geological, geochemical and mineralogical features of the Miocene lacustrine gypsiferous sediments were investigated in order; a) to understand the origin of different evaporite-bearing uppermost Miocene series, b) to demonstrate lateral evaporite facies changes in playa-lake environments and c) to search trace element contents of different gypsum occurrences for a better depositional model.

Geologic setting

The oldest rocks in the study area are the Kuzören Metamorphic rocks, which consist of micaschists, calcschists, phyllite, sand, marbles, Arayıt Limestones; both series are of Paleozoic age (Fig. 2). The Upper Cretaceous ultrabasics has been overturned and overthrust upon the Paleozoic Kuzören metamorphic rocks, and is made of ophiolite melange including gabbro (troktolite), pyroxenite (clinopyroxene and verlite), dunite and peridotite (ASUTAY et al. 1989).

The Late Upper Cretaceous Sivrihisar plutonic rocks consist of granite and, micaceous and porphyritic granodiorites, which are rich in feldspar and amphibolite (ERDINÇ 1978). Dissolution of these feldspars in compositions of orthoclase, albite, oligoclase and andesine partially controlled ground water chemistry. During the Late Miocene-Early Pliocene, volcanism provided mainly tuffs and minor amount of volcanic breccia, aglomerate and lava flows of dacite, trachyte and trachyandesite in composition that were emplaced during different episodes. According to KULAKSIZ (1981), Late Cretaceous granodiorite and quartz veins; Paleogene phonolite and trachyte and Jurassic-Cretaceous mafic volcanics of spilite-diabases; Paleozoic marble schists, metabasites and lawsonite–glaucophane schist are exposed to the north of Sivrihisar area.

The Eskişehir basin is developed as accretionary complex after southward ophiolite obduction during the Upper Cretaceous and the basin became a fore-deep during the end of the same period. The collision zone in the region of Eskişehir is clearly associated with HP–LT blueschists and hence is considered as a major tectonic "suture zone" is separating the collided continents occurring in the Late Cretaceous (MONOD et al. 1991). Rift development of the Aegean region and young volcanism strongly affected the Eskişehir basin during the Middle Eocene and the rocks were folded regionally at the end of Upper Eocene. During the Oligocene, the basin was under the influence of regional peneplain and young tectonism of the rapid extension regime of Aegean region thins the crust and the lithosphere over a large region that caused to develop Eskişehir lake in the study area at the Lower Miocene.

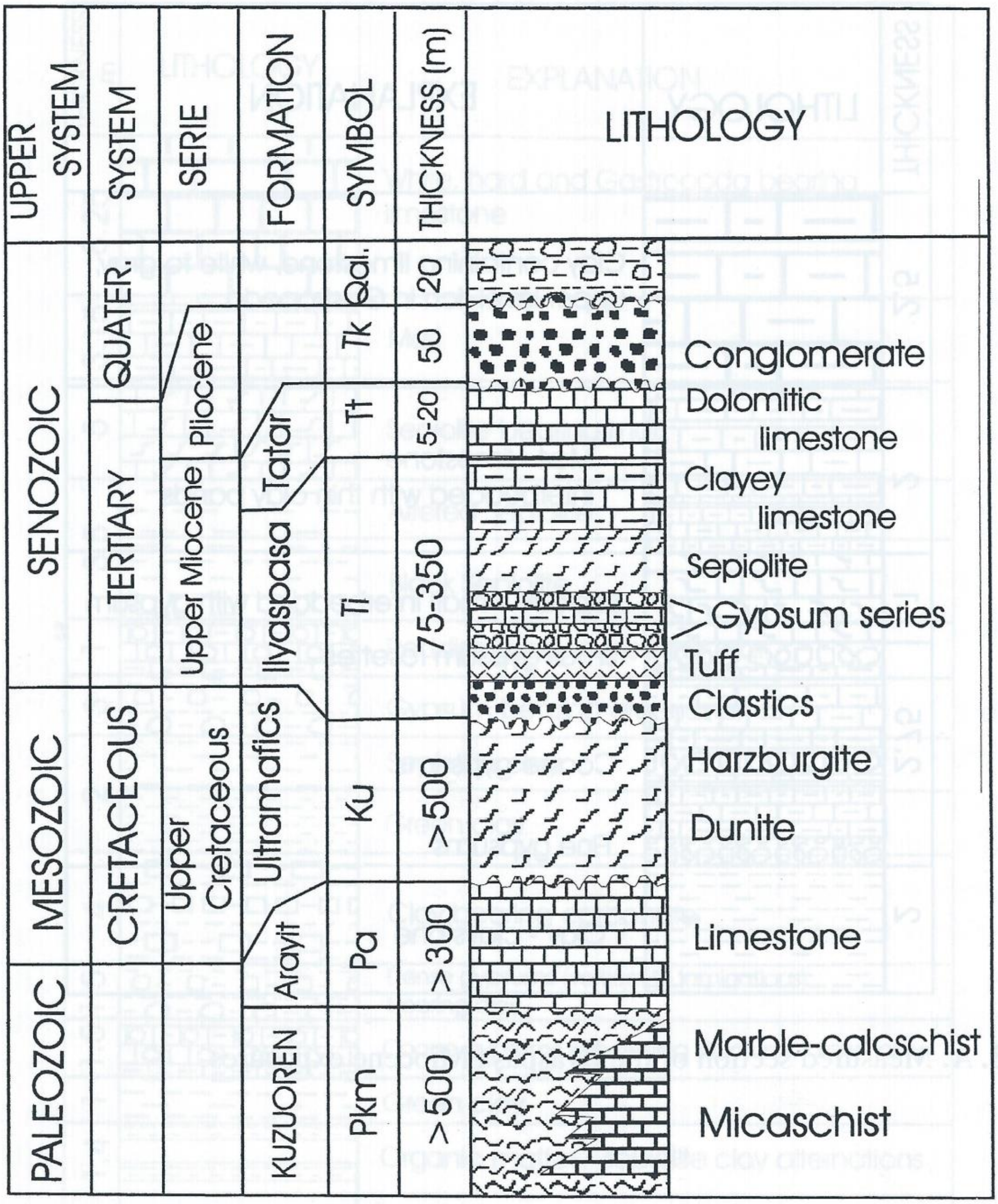

Fig. 2. Stratigraphic section of exposed Miocene rocks in the study area, as exposed south of Sivrihisar.

The Miocene basin setting lies on an ophiolite complex and the basin was developed as a post-collisional collapsed basin. Some E–W trending growth faults observed in the mining boreholes of sepiolite deposits and the Eskişehir lacustrine basin exhibit basin-in-basin structure (McKenzie & Yilmaz 1991). The Miocene basins had been formed because of westward motion of the Anatolian Block under the effect of the northward pushing of

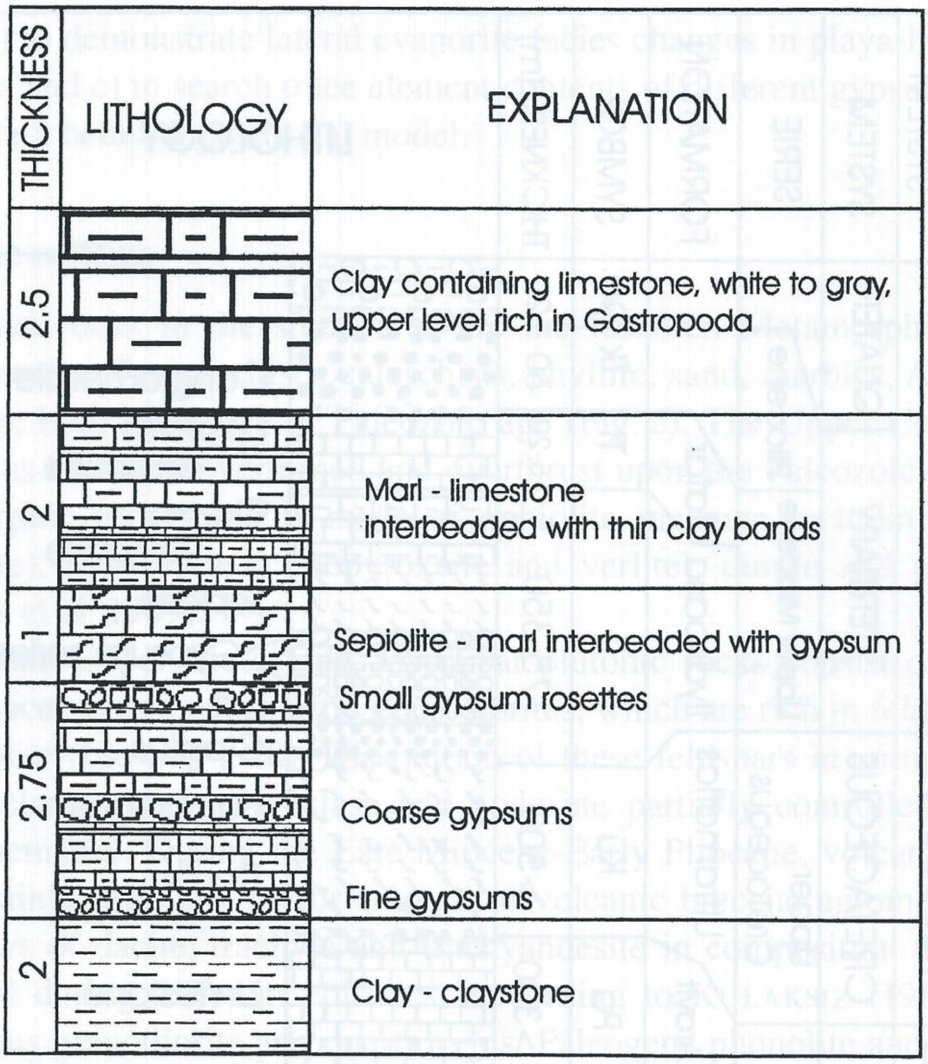

Fig. 3. A. Measured section of the İlyaspaşa Miocene exposures.

the Arabian Platform. All these tectonic regimes had been resulted in an extension in the Aegean region.

The İlyaspaşa section exhibits the best exposure of Miocene deposits 30 km south of Sivrihisar and consists of conglomerates, sandstones, tuff/tuffites, gypsums, clayey limestone, sepiolites, and clays/claystones (Fig. 2). This series of deposits is overlain by the Pliocene, composed of loosely cemented conglomerates and sandstones. The gypsums have been recorded in the İlyaspaşa section, as alternating with clay/claystones and tuff/tuffites, and interbedded with Mg-poor and Mg-rich dolomites. This unit exhibits a cyclic sedimentary character from the bottom to the top throughout the basin.

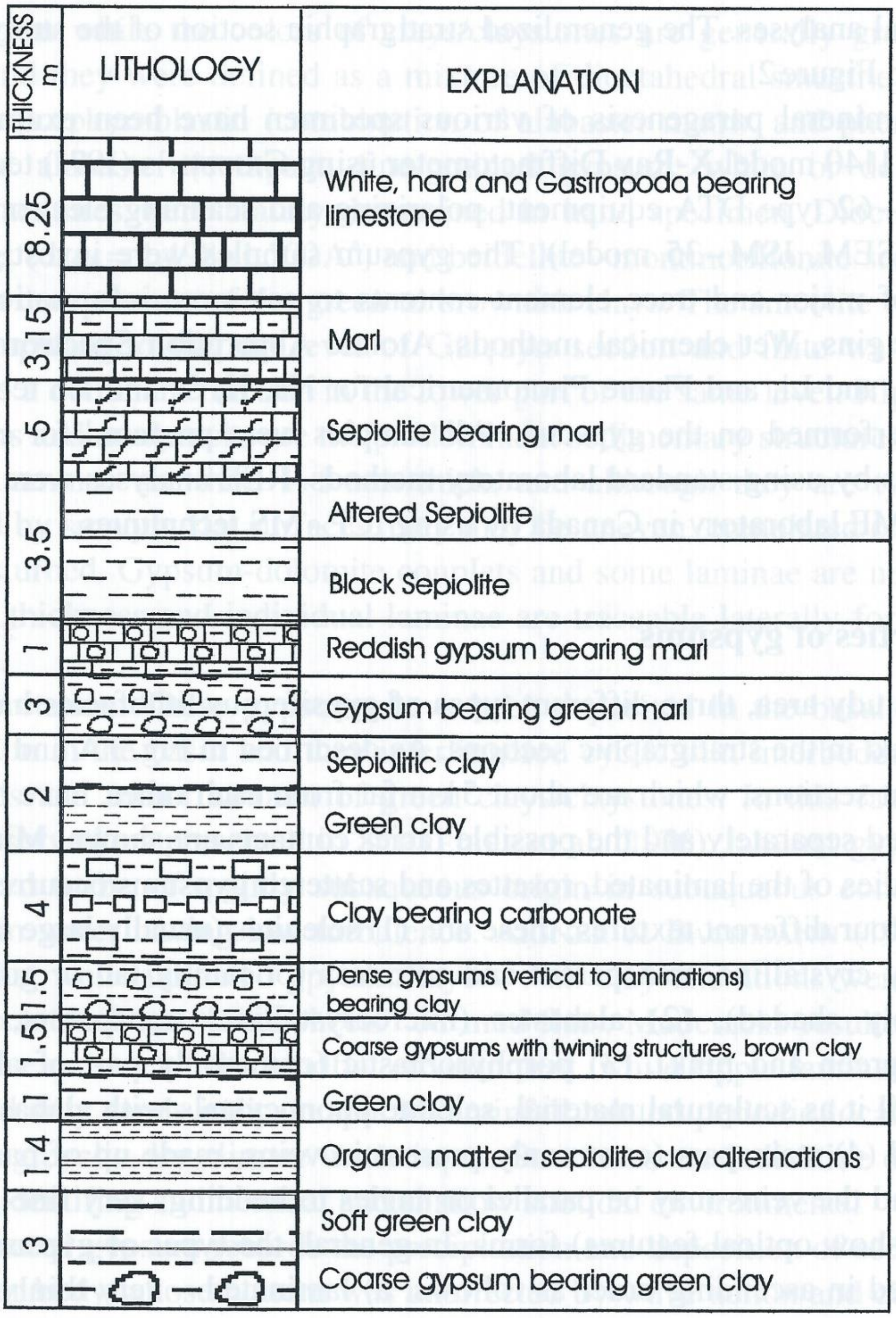

Fig. 3. B. Measured section of the Gülçayır Miocene exposures.

Materials and methods

More than 100 samples of conglomerate, sandstone, limestone, altered tuffs, clay–claystone, sepiolite together with gypsums were collected from the different stratigraphic sections and they were chosen for petrographic and chemical analyses. The generalized stratigraphic section of the study area is given in Figure 2.

The mineral paragenesis of various specimen have been examined by Philips 1140 model X-Ray Diffractometer using GRIFFIN's (1971) technique, Linseis–62 type DTA equipment, polarizing and scanning electron microscope (SEM, JSM–35 model). The gypsum samples were investigated in terms of major and trace element contents to get more information about their origins. Wet chemical methods, Atomic Absorption Spectrometer for Mg, Al, and Li, and Flame Photometrical for Na, K, Sr and Rb techniques were performed on the gypsums. All samples were prepared for chemical analyses by using standard laboratory methods. REE analyses were done in the ACME laboratory in Canada by using ICP–MS techniques.

Properties of gypsums

In the study area, three different types of gypsiferous lithofacies have been identified in the stratigraphic sections. As described in Fig. 3 A and 3 B, two different sections, which are about 5 km far from each other, have been exemplified separately and the possible facies contacts are shown. Mineralogical studies of the laminated, rosettes and scattered gypsums occurrences revealed four different textures; these are, (1) selenites (usually large creptaes, coarsely crystalline, transparent and colorless (or faintly tan or golden) or delicately shaded), (2) alabaster (microcrystalline, transparent, usually white, green and pink), (3) porphyroblastic (commonly part of alabastar, but spoil it as sculptural material, selenite phonocystals with alabaster matrix) and (4) stainspars (commonly present in veins, made up of parallel fibers, and the veins may be parallel or angles to bedding; very fine-grained, do not show optical features) forms. In general, the types of gypsums were classified in ascending order as follows: a) laminated – very thinly bedded gypsum, b) rosette gypsum and c) scattered gypsum facies.

a) Laminated – thinly bedded gypsum facies

These gypsums are thinly interbedded with dolomitic marl and minor amount of green clays/claystones, and have been deposited cyclically in the lowest part of the sequence. These kinds of gypsums are widely distributed in Kuşaklıbayır District and they contain small amount of organic matter. The laminated – very thinly bedded gypsums were exposed and total thickness ranges from 2 to 70 cm in various exposures. Gypsums are white and light brown while the colors of clays/claystones are generally green and brown and they were defined as a mixture of dioctahedral smectite and illite. The porphyroblastic (combination of alabaster matrix and phenocrystals) and alabaster (compact, fine-grained gypsum; white or delicately shaded) textures were mainly determined in hand specimen. Dioctahedral smectites (d_{060} = 1.498–1.500 A°) and beidellite–montmorillonite series are the main components of the green to brownish clays. The smectite ratio increases upward to the top level of Gülçayır section and illite was determined as a dominant fraction in the lower part of the same level. Ripple laminations and mudcracks are the predominant sedimentary structures in this facies. Laminae are thin, 1–5 mm thick, and although they are typically bounded by smooth, flat surfaces, they may be uneven, crenulated or plastically disturbed. Gypsum-dolomite couplets and some laminae are nearly of uniform thickness and individual laminae are traceable laterally for a long distance.

Interpretation: These gypsums have been deposited in the basal part of the section in the basin and they interfingered cyclic thin interbedded with dolomites and minor amount of green clays/claystones. In this facies, by using observations presented in SCHREIBER et al. (1976), laminar gypsum is interpreted to be of mainly subaqueous origin in subaqueous conditions, formed in water having low turbulence. AIGNER & BACHMANN (1989) reported that well laminated gpysum layers with clay alterations were probably deposited from "brine-sheets" on mud flats. Mudcracks resulted from subaerial exposure of the mudflat environment, while ripple laminations in clays and silty sands indicate sporadic rainfall related periodic local flooding during cyclic dry climate water input. Structures are indicative of wave actions, identifing an intertidal and shallow subtidal environments.

Laminated gypsum records the precipitation and deposition of sediments in a water body whose bottom was unaffected by wave action and currents. Such stagnant, permanently stratified water bodies need not be particularly deep and carbonate laminae form in comparatively shallow waters than that from the Dead Sea as a result of "whitings" at the brine surface (NEEV & EMERY 1967), however, they can also form under deeper conditions.

b) Rosette gypsum facies

This type of gypsum has been generally observed between laminated and scattered gypsum levels in the upper part of the Gülçayır section and is particularly the most widespread in the central part of the Miocene lake. The

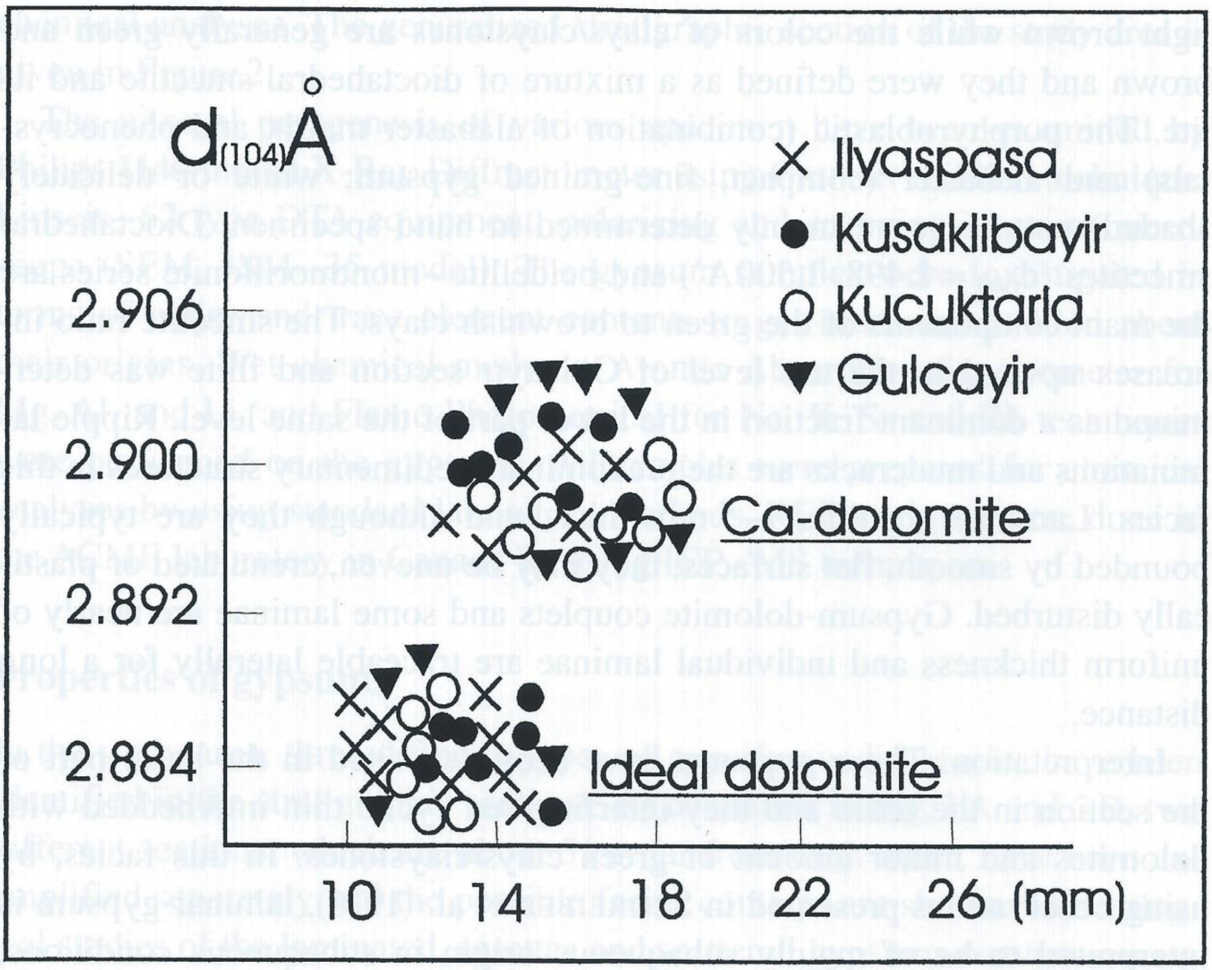

Fig. 4. Comparison of XRD data for the average value of d104 and width of half-height of the same peak (104) in terms of mm, according to GRAF & GOLDSMITH (1958). X: Küçüktarla, ●: Kuşaklıbayır, +: Gülçayır and ○: İlyaspaşa.

thickness of this facies is between 20 and 60 cm and gypsum clusters occur alternating with the sepiolitic clay/claystones and marl-dolomitic carbonate levels. Their colors range from white to light brown, depending on the locations. The white gypsums were most common near the base of the Küçüktarla section and selenitic crystals in that zone are up to 20 cm in length. Gypsum beds are uniform, locally intercalated with claystones, and have a macrocrystalline texture. Locally, well preserved, horizontal beds and vertically orientated crystals can be recognized even from long distance.

At the top level, the color of the gypsums is generally brown and the dimension of crystals is quite small and these occurrences are interbedded with carbonates. Their dimensions are not larger than 5 cm. Rosette shaped gypsums are typically observed in a quarry in the Gülçayır district and 11 cyclic gypsum sequences are observed (Fig. 3 B). In the same quarry, high walls of sepiolite bearing strata exhibit different colors, mainly white, brown and black. The carbonate minerals that are present in the uppermost levels of the quarry are mainly dolomite, calcite and minor amount of magnesite. Dolomites are finely crystalline rhombs and white. XRD studies have revealed that dolomites are in ideal crystallographic structures and the average of d_{014} value is 2.887A° (Fig. 4).

Interpretation: Gypsum crystal growth with carbonates and clays suggest precipitation of primary gypsum crystals under very shallow subaqueous conditions (SCHREIBER et al. 1976, KENDALL 1984, AIGNER & BACHMANN 1989), probably in a playa lake. Experimental synthesis of this geological model has been investigated in simulated muddy environments under laboratory conditions (CODY 1976) and he found that gypsum and bassanite were the only sulphate species produced within Wyoming bentonite gels and pastes from pore solutions containing as much as 20 % NaCl at 8°–80 °C temperature interval. Furthermore, CODY (1976) discovered that the experiments were unable to nucleate and grow primary anhydrite under a wide range of conditions designed to closely simulate natural environments. Secondly, the formation of gypsum crystals in his experiments that was tabular perpendicular to the crystallographic c-axis.

The presence of both selenitic gypsum and idiotopic arrow-head twinned crystals (chevron structure) indicate continuous crystal growth during deposition and selenitic crystals reflect seasonal changes in brine composition (CIARAPICA et al. 1985). YOUSSEF (1988) reported that the decreasing volume of the brine pond and, consequently, an increase of salinity, controlled the crystal size of gypsum. In addition, porosity and permeability of sediments have significant impact on crystal growth mechanisms. Fluctuation of lake level and cyclic changes in pore water chemistry could cause "evaporative pumping" effect in highly porous and permeable sediments where ground water table is probably close to the surface of sediments.

c) Scattered gypsum facies

This type of gypsum has been observed in the uppermost parts of the gypsiferous Neogene formation in the basin. The gypsums were found within the carbonate unit where thick-bedded dolomite, dolomitic limestone and claystone are the main lithologies. Dolomites are porous, unconsolidated and the average thickness of this facies is about 10 m and maximum is 20 m.

Scattered gypsum crystals have been observed coexisting with calcite, dolomite and clay minerals. This type of gypsum was observed especially in clayey dolomites and they exhibit macrocrystalline textures in few cm, together with euhedral structures, twinned crystals and maximum length of the gypsum crystals is about 10 cm. This type of gypsum is found in the uppermost parts of almost all sections and is especially common in Balıklıdam district. Smectites are dominant in clayey horizons; quartz, opal–CT and feldspars are the other observed minerals in this facies.

Interpretation: Continuing evaporation in the uppermost part of the stratigraphic succession and evapotranspiration generated a significant pore water concentration gradient towards the basin. Super saturation in pore water should be expected with respect to calcite cement, soft very fine-grained, high Mg–calcite or Ca–dolomite and protodolomite in playa lakes. Due to increasing in saturation levels, and pisolitic caliches development when precipitation occurs from surface waters associated with peripheral springs, these carbonates should be considered as of evaporate origin because they formed in the same way as gypsum formed within the basin (Kendall 1980). Playa-lake flats commonly have a muddy platform where sediments are kept permanently moist due to by the groundwater discharge (Eugster & Hardie 1975). Gypsum precipitation is layer carbonate deposition and the existences of very fine-grained gypsum indicate subaerial to continental sabkha environment. Needle shape crystals precipitate in shallow brine bonds, but they are not diagnostic of water depth. Halite is not found in the study area, probably due to lack of chloride and sodium or it easily washes out.

Cody (1979) demonstrated in laboratory experiments that the presence of certain types of dissolved organic material is the major factor promoting growth of lenticular gypsum habit rather than warm saline water conditions. His experiments utilizing diffusion-controlled growth of gypsum within sediments of various types, and also utilizing evaporation-controlled solution growth indicate that this organic material promotes the growth of lenticular gypsum, but only under alkaline conditions. In acid conditions, only elongate prismatic gypsum develops which is independent from the presence or absence of plant materials. Cody's (1979) experiments explain why lenticular gypsum forms in some instances, and prismatic gypsum in others, within natural sedimentary environments.

In addition, Cody & Cody (1988) experimentally demonstrated that prismatic gypsum typically grew at both high and low temperature in the absence of organic additive. With increasing tannic acid concentrations, the prismatic crystals progressively became flattened and two [(a) < 15 °C and (b) > 35 °C] temperature-dependent trends developed. At low temperatures, a hemi-bipyramidal habit dominated, whereas the lenticular dominated habit formed at higher temperatures. As organic matter concentration increases, twin gypsum crystals developed, and finally rosette aggregates formed. Higher temperatures generally favored better-formed and larger rosettes (Cody & Cody 1988).

Geochemical approaches

Geochemical studies have been performed to collect more data in order to describe the probable ways of formation of gypsum occurrences and in all samples that were taken from the four different locations and three different types of gypsum occurrences. The results of geochemical analyses are given Table 1.

The trace element contents and Na/Mg ratios of the gypsums were examined and their distributions in different geographic locations. The rosette samples from Gülçayır and Küçüktarla locations exhibit similar Na/Mg ratios, as seen in Table 1. The samples of Küçüktarla and İlyaspaşa are slightly different from those of the latter two exposures because it contains less Na and slightly higher Mg concentrations. This behavior of the studied trace elements may be related to a similarity in environment of deposition in the same episode. It is regarded to the range of the total trace element contents in the gypsums as another parameter, which may be used in the determination of depositional conditions. The scattered gypsum samples of Küçüktarla and İlyaspaşa exhibit a slightly different behavior in Table 1.

The trace and rare earth element data for the gypsum samples, and samples (7 and 8) from Oğlakça open-pit gypsum mine, which is located 100 km farther to the NE of the study area, are presented in Table 1. Using geochemical data for genetic comparisons, as shown in Figs. 5, 6 and 7, the main purpose is to document which elements came from hydrothermally occurred gypsum mine and which others from leaching of volcanic rocks (dacite, trachyte and trachyandesite) in the vicinity of Miocene lake. The REE and trace element data indicate that some rare earth elements (Sc, Co, Ni, Th, Li, Na, K, Fe, U, Ce, Cr, Sm, Eu, Nd, Br, Au) in gypsum crystals came from the Upper Miocene volcanic rocks in surrounding high lands of lacustrine basin. However, other trace elements (Ca, Sr, Zn, Ba, and SO4)

Table 1. Trace and Rare Earth Element Contents of Gypsum Samples (ppm). Samples 1 and 4 are laminated gypsum from Kuçaklıbayır area; samples 2 and 5 are rosette gypsum from Gülçayır and Küçüktarla areas, samples 3 and 6 are scattered gypsum from Küçüktarla and İlyaspaşa areas, respectively. Samples 7 and 8 are from Oğlakça open-pit gypsum mine.

Sample No.	Au	Ag	As	Ba	Br	Ca %	Co	Cr	Cs	Fe %	Hf	Hg	Ir	Mo
1	17	<5	21	530	200	17	13	430	<2	1.9	4	<1	<5	<5
2	23	<5	<2	550	740	6	13	190	5	2.2	<1	<1	<5	<5
3	12	<5	2	190	81	27	8	210	<2	0.3	<1	<1	<5	<5
4	19	<5	28	420	340	30	15	680	<2	0.1	<1	<1	<5	<5
5	25	<5	<2	610	780	24	7	340	<2	0.1	<1	<1	<5	<5
6	15	<5	6	240	105	28	9	450	<2	0.1	<1	<1	<5	<5
7	3	<5	<2	1660	<1	39	<5	<10	<2	0.1	<1	<1	<5	<5
8	2	<5	<2	1700	<1	41	<5	<10	<2	0.1	<1	<1	<5	<5

Sample No.	Na %	Ni	Rb	Sb	K	Li	Sc	Se	Sn	Sr	Ta	Th	U	W
1	4.93	160	<30	0.8	800	17	5.9	<5	<1	5	<1	8.2	4.5	<4
2	10.10	35	<30	<0.3	535	5	7.0	<5	<1	5	<1	9.1	6.9	<4
3	2.14	25	<30	1.8	750	12	6.0	<5	<1	5	<1	10.5	5.8	<4
4	5.68	170	<30	<0.2	840	15	8.2	<5	<1	5	<1	12.5	5.9	<4
5	9.55	42	<30	<0.2	560	10	9.0	<5	<1	5	<1	10.5	8.3	<4
6	2.50	45	<30	0.3	710	14	7.8	<5	<1	5	<1	8.5	8.2	<4
7	<0.05	<50	<30	0.3	21	<2	0.2	<5	<1	58	<1	4.5	<0.5	<4
8	<0.09	<50	<30	0.4	27	<2	0.4	<5	<1	46	<1	5.2	<0.5	<4

Sample No.	Zn	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Al	Mg	Na/Mg
1	<50	31	54	33	3.2	0.9	<0.5	1.5	0.23	210	550	90
2	<50	29	50	25	2.6	0.7	<0.5	1.9	0.27	150	900	112
3	<50	16	43	27	3.1	0.7	<0.5	1.2	<0.05	100	750	29
4	<50	37	67	35	4.1	0.2	<0.5	1.7	<0.05	230	600	95
5	<50	34	47	32	8.2	0.8	<0.5	2.0	<0.05	135	870	110
6	<50	17	53	45	6.2	1.0	<0.5	1.4	<0.05	220	700	35
7	243	27	33	9	2.1	0.8	<0.5	2.4	<0.05	50	70	1
8	118	21	31	8	2.3	0.7	0.7	2.2	0.33	60	80	1

more likely came from the Oğlakça gypsum mine, transported by rivers into the lake (Figs. 5, 6 and 7).

Some samples are more enriched in rare earth element concentrations than others. They are poorly to strongly enriched in highly incompatible

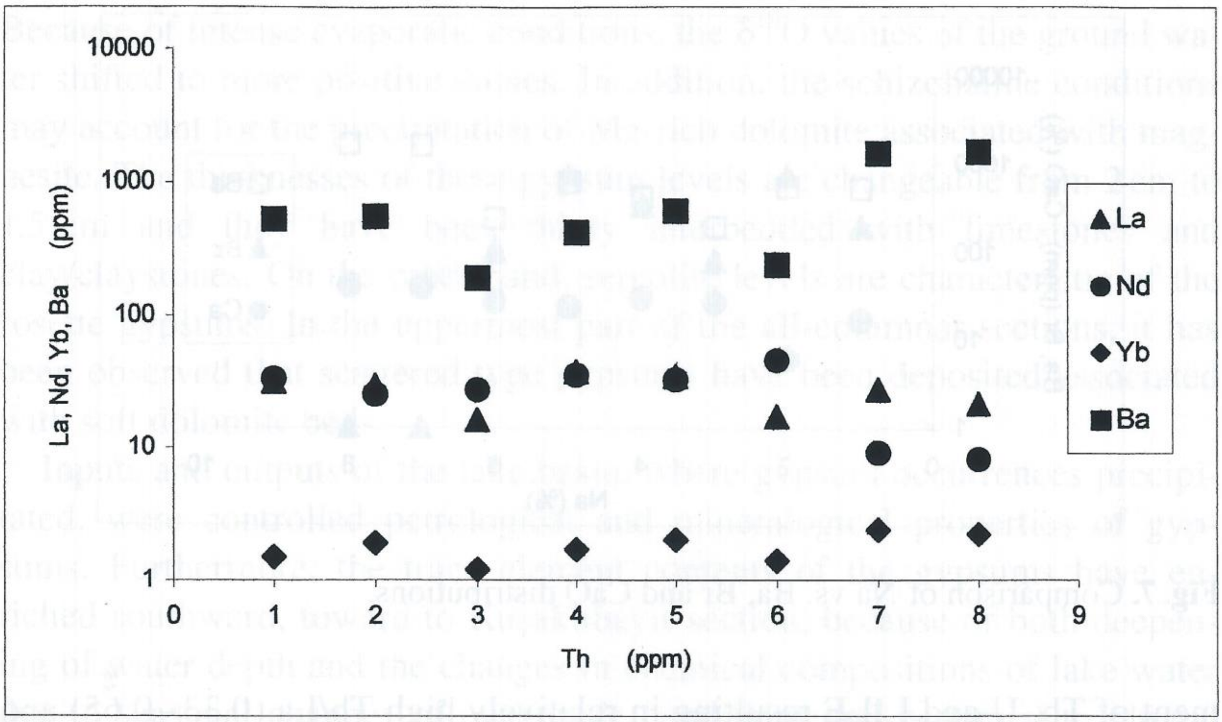

Fig. 5. Comparison of Th vs. La, Nd, Yb and Ba distributions.

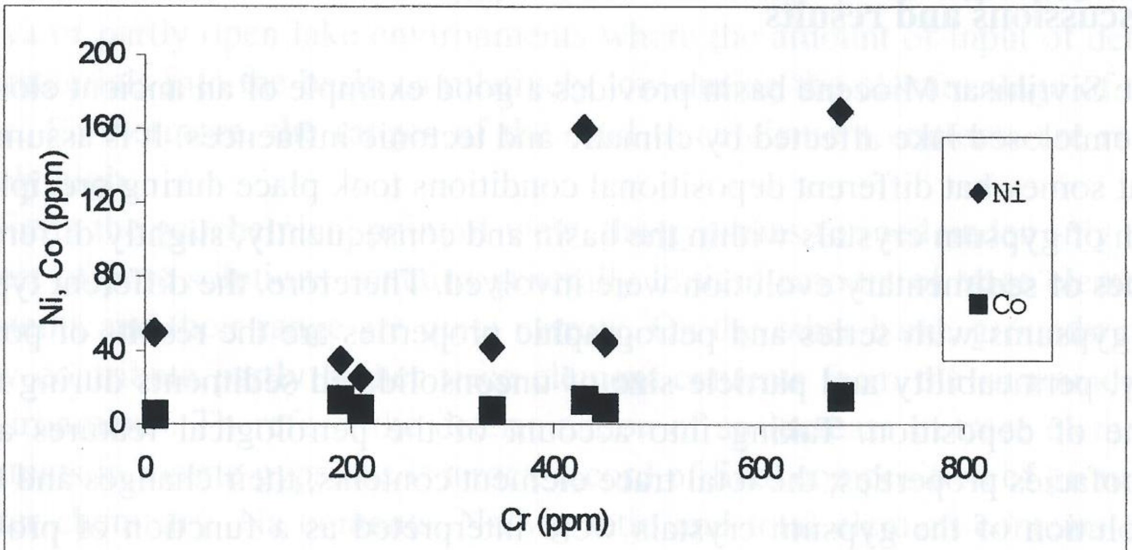

Fig. 6. Comparison of Cr vs. Ni and Co distributions.

elements (Ba = <100–1700 ppm, Th = 4.5–12.5 ppm, La = 17–31 ppm), yielding high Th/Yb (1.87–875) ratio. The significant features of the calc-–alkaline volcanic rocks are enriched in LILE over LREE and MREE, resulting in relatively high Ba/La (17–36) and Th/La (0.33–0.65) ratios. Also, trace element features of the volcanic rocks are characteristics of coenrich-

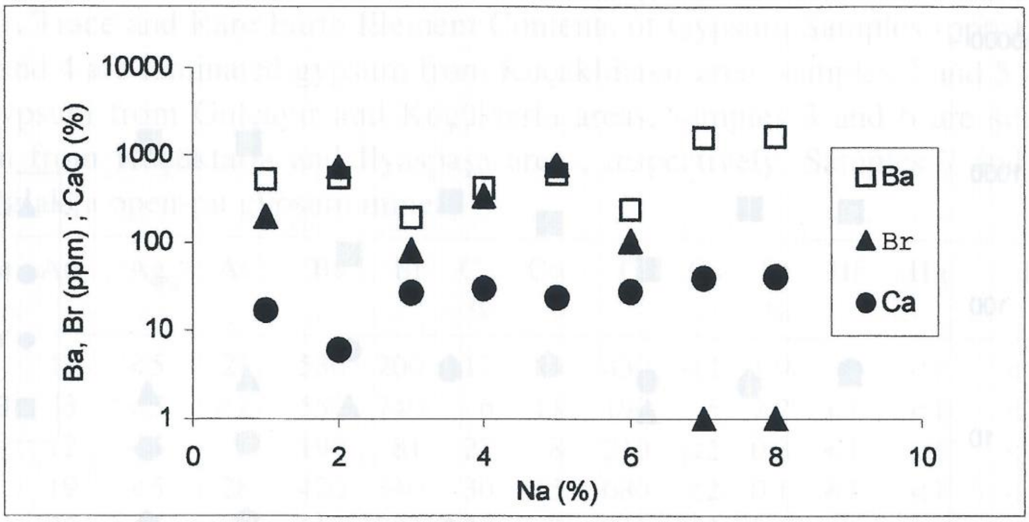

Fig. 7. Comparison of Na vs. Ba, Br and CaO distributions.

ment of Th, U and LILE resulting in relatively high Th/La (0.33–0.65) and Ba/La (17–36) ratios (Table 1).

Discussions and results

The Sivrihisar Miocene basin provides a good example of an ancient closed – semiclosed lake affected by climatic and tectonic influences. It is assumed that somewhat different depositional conditions took place during precipitation of gypsum crystals within the basin and consequently, slightly different types of sedimentary evolution were involved. Therefore, the different types of gypsums with series and petrographic properties are the results of porosity, permeability and particle size of unconsolidated sediments during the time of deposition. Taking into account of the petrological features and lithofacies properties; the total trace element contents, their changes and the evolution of the gypsum crystals were interpreted as a function of provenance of trace elements and cyclic fluctuations of groundwater table. The lateral and vertical changes in the gypsum facies and levels were summarized on measured stratigraphic sections in Fig. 3 A and B. The laminated-bedded gypsums are present in the lowest part of the section. The rosette gypsum was observed in the upper parts of the laminated-bedded gypsum levels.

Bellanca et al. (1993) discussed C and O isotopic data that the lowest $\delta^{18}O$ values (– 6 to – 1 %°) of dolomites associated with sepiolite the heaviest $\delta^{18}O$ values (– 4 to + 2 %°) associated with magnesite or gypsum.

Because of intense evaporatic conditions, the $\delta^{18}O$ values of the ground water shifted to more positive values. In addition, the schizohaline conditions may account for the precipitation of Mg-rich dolomite associated with magnesite. The thicknesses of these gypsum levels are changeable from 2 cm to 1.5 cm and they have been thinly interbedded with limestones and clay/claystones. On the other hand, sepiolite levels are characteristic of the rosette gypsums. In the uppermost part of the all-columnar sections, it has been observed that scattered type gypsums have been deposited associated with soft dolomite beds.

Inputs and outputs of the lake basin, where gypsum occurrences precipitated, were controlled petrological and mineralogical properties of gypsums. Furthermore, the trace element contents of the gypsums have enriched southward, toward to Kuşaklıbayır section, because of both deepening of water depth and the changes in chemical compositions of lake water due to seasonal changes of evaporatic conditions and perennial to pluvial characters of cyclic climatic influences.

As a result of our field observations together with the geologic and chemical data; *the laminated* gypsums are assumed to be deposited in a playa or partly open lake environments where the amount of input of detritic materials into the basin as relatively low during the closure stage of the lake. Furthermore, the ranges of the total trace element contents are relatively high.

From the geochemical point of view, the gypsums formed under only the effect of pore solutions contains generally limited amount of trace element contents and their range are quite narrow. On the other hand, groundwater may contribute partly higher trace element contents from the surrounding environments. Therefore, the determination of an increase in trace element contents in rosette gypsums is a rock record of final composition of groundwater chemistry. Na contents, Na/Mg ratio and total element contents are somewhat higher in rosette gypsum than those of laminated gypsums. Finally, scattered gypsums have been formed as a result of typical ground water that had a good deal of $CaSO_4$ in solution during intervals of drying scattered gypsum crystals. The fluctuation of water table was also noticed in the trace element contents due to the solution input and the different thickness of the gypsums.

MÜLLER et al. (1972) proposed a geochemical model for the lacustrine carbonates as follows: (a) The Mg/Ca ratio is low in lake water (<2), low Mg–calcite is precipitated, (b) the ratio is between 2 and about 7, high

Mg–calcite precipitates, (c) the ratio about 7, but less than about 12, high Mg–calcite is the primary mineral, (d) the ratio is higher than about 12, aragonite precipitates and (e) at very high Mg/Ca ratios and high Mg concentrations, hydrous Mg carbonates can be expected. MÜLLER et al. (1972) suggested that the formation of carbonates might be regarded as a series leading from high Mg–calcite → dolomite → huntite → magnesite with increasing Mg/Ca ratios in the solution. Using MÜLLER's model, the presence of soft dolomite beds indicates that Mg/Ca ratio was between 7 and 12 in the Miocene Eskişehir lake water.

Gypsum associated with protodolomite, contains a high Sr concentration and may have formed as a by-product of dolomitization in Holocene Sabkha environment, Abu Dhabi, Persian Gulf (BUTLER 1969). He proposed that aragonite, gypsum, anhydrite and protodolomite, and brine chemistry are broadly consistent with the following origins. The origin of gypsum is primary precipitation, replacement of aragonite and replacement of aragonite via dolomitization process, and origin of protodolomite is related to the reaction of Mg in brines with host aragonite sediments. However, no aragonite sediments are found in the study area.

By taking into account these results and observations, we have concluded that in *Kuşaklıbayır* location, the formations and deposition episodes of gypsums formed under similar conditions. The gypsums observed in *Küçüktarla* and *İlyaspaşa* locations are differing from the above district in term of the depositional environments. In these locations, generally three main gypsum deposition periods have been worked out, these are mostly closed playa lake conditions and also underground water-controlled formations have occurred. These conditions have been alternated at least twice or more.

İlyaspaşa is the only location where the scattered gypsums were observed, possibly due to very high evaporative conditions in a very limited period of time. The area was very shallow and marginal part of the basin. In the *İlyaspaşa*, we have determined high levels of scattered gypsums, moderate level trace element contents and low Na/Mg ratio.

Possibly, *Kuşaklıbayır* is, from the playa point of the basin, slightly deep; therefore laminated gypsums are common. In this location, the total trace element contents and Na/Mg ratio are moderate. It is regarded to these gypsums as a typical example of the playa type occurrences. In the *Gülçayır* and *Küçüktarla* locations, underground water and pore solutions was more effective than that of *Kuşaklıbayır* region; then rosette gypsums and scattered gypsums are more common and they have formed within two different levels. Consequently, in these two locations, as a result of water chemistry and trace element contents, Na/Mg ratio is higher than *Kuşaklıbayır* locations.

Küçüktarla region is the most restricted area where the depositional conditions have been subjected to rapid changes, for these reasons playa and groundwater conditions are not yielded. Then scattered gypsums are common, although the other types are quite rare. Thick gastropoda-rich calicte zone indicates changes in salinity content due to freshwater influx into the dry lake. Soft and fine-grained dolomites exhibiting diatom remnants and root fragments have been formed during periods of fluctuating lake level and environmental conditions ranging from saline to schizohaline.

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