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GEOLOGY AND ORIGIN OF THE ALBITE DEPOSITE OF THE ÇİNE SUBMASSIF, SOUTHERN MENDERES MASSIF (SW-TURKEY)

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ABSTRACT.- Around 250 albite occurrences are recorded in the Cine Submassif that represents the southern part of the Menderes Massif, from where annually 1.7 million tons of Na-feldspar is produced. The study area is covered by the widespread exposures of the Pan-African Precambrian core-complex of the southern Menderes Massif. The albite deposits are mainly within the meta-pegmatites, located along NNW-SSE trending tectonic zones. In this study, the effects of the Alpine metamorphic and metasomatic events on the albitization process are discussed, and the importance of the younger intrusives within the Cine Submassif are emphasized. Moreover, the geometry, dimensions and petrologic properties of the albite deposits are explained and the quality of the various market products is documented.

INTRODUCTION

It is noticeable that large production of albite at the southern part of the Menderes Massif has been obtained during the last ten years. This is also indicated by the fact that Turkey is now one of the leading feldspar producing countries in the world. Although the albite occurrences have been known since 1950, the earliest production towards the end of 1960's was mainly for the glass industry. Albite mining developed and production has increased in Çine-Milas-Söke-Yatağan-Karpuzlu regions since 1980's.

It is known that around 250 feldspar deposits are present in the region known as Cine Submassif. About 100 of these deposits are located within the area of which the authors company has the mining license. Since 1987, with the foundation of the company's production site in Milas, albite production capacity of 850 000 (650 000 tones of raw ore, 25 000 tones of grinded ore and 225 000 tones of flotation product) tones per year (t/y) has been achieved with the mining activities in the 15 quarries in the study area.

The presented results of this study includes the recent investigations of the authors in the recent years and include; remote sensing studies by satellite images, photogeology, fieldwork, prospecting, detailed geological mapping, drilling, trenching, and a series of geochemical work including technological studies. In this study, the authors aim to share their data and experiences with studies interested on regional and local geology related to. the albite exploration and production, and discuss the origin, geometry and mineralogy of the albite deposits, and the effects of these criteria on the quality of the products.

GEOLOGY OF THE ALBITE DEPOSITS

The Menderes Massif in the western Anatolia is situated between Lycian Nappes in the south and the Neotethyan İzmir-Ankara belt in the north. The geological studies of the area since 1950's have been summarized by Candan and Dora (1998) in detail. According to these authors, Menderes Massif is mainly composed of a Pan-African basement called as the "core" and an overlying "cover" series of Early Paleozoic-Paleogene age. The "core" units are mainly composed of silisiclastic metasedimentary rocks, leptitic gneisses and migmatites of felsic volcanic origin, and metagranites and metagabbros which cut through these rocks. Within the metasedimentary cover units, carbonates are dominant at the top and silisiclastics at the bottom (Candan and Dora, 1998).

By the studies of Satır and Friedrichsen (1986), Hetzel and Reischmann (1996), and Candan and Dora (1998) the polymetamorphic history of the Menderes Massif can be summarized in two main periods;

a) A high temperature granulite - high pressure eclogite fades metamorphic event based on zircon age (~550 my) from Precambrian core,

b) A high pressure epidote / blueschist / eclogite facies metamorphic event based on Tertiary mica (43-37 my) ages.

The part of the Menderes Massif situated to the south of the Büyük Menderes Graben is known as the Cine Submassif. Albite deposits are especially widespread in the southern part of the Cine Submassif (Fig. 1). The rich albite deposits in the region were assigned for the first time by Graciansky (1965), who indicated the Karadere Belt of the present study as an

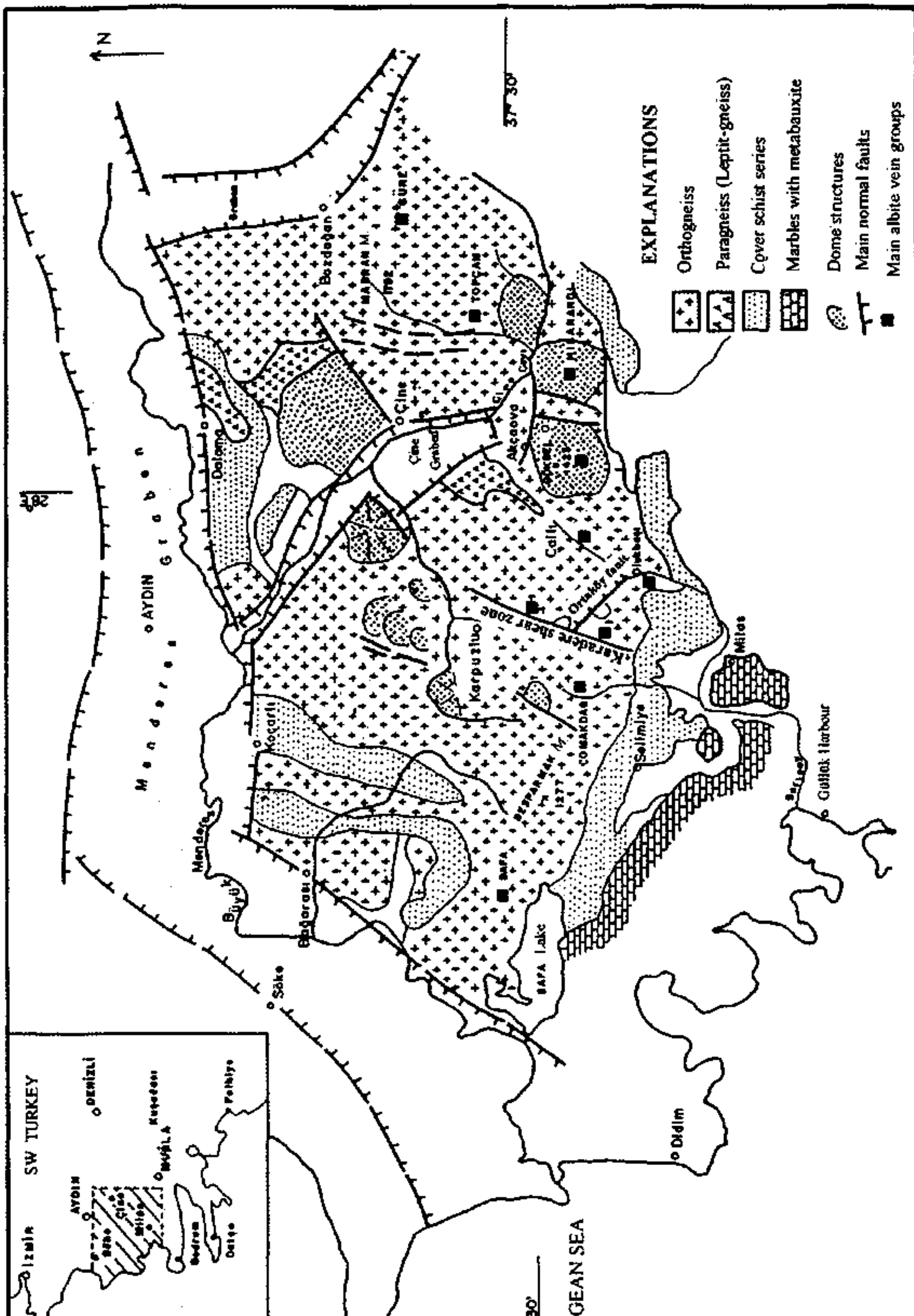

Fig. 1- Geological sketch-map of the Çine Submassif (Menderes Massif-SW-Turkey). The contacts of some units are from Candan and Dora (1998).

assemblage of "partly kaolinized, fine grained albite gneiss with muscovite". Beside the Çine Submassif, albite deposits are also known around Nazilli-Beydağ and Buldan in the north. However, they are not important in terms of their reserves and quality. Çine Submassif is composed of both coarse-grained augen gneisses and fine grained micarich gneisses. The augen gneisses with typical augen-shaped K-feldspar porphyroblasts display a well-developed granite morphology and are interpreted as metagranites due to their petrographic properties. The studies carried out on the satellite images of the Çine Submassif, that is generally indicated as a core complex by Bozkurt et al., (1993) clearly show the presence of at least 10 intrusives or dome-shaped structures (Fig. 1). The petrographic properties of these intrusive and dome structures can vary from one case to the other, e.g. the Gökbel Pluton to the west of Hisarardı that has different properties in terms of color and texture is characterized by K-feldspar veins with tourmaline and quartz rather than albite.

The albite occurrences that are concentrated at the southern part of the Çine Submassif are collected from west to east under the groups of Bafa-Çomakdağ-Karadere-Olukbaşı-Çallı-Gökbel-Hisarardı-Karpuzlu-Topçam-Güre, respectively, by conformity with their alignment along NNE-SSW trending main tectonic lines that are dominant in the region (Fig. 1). The Karadere Group, the largest one in the study area, is located on a 20 km long, N10°E trending shear zone, extending from north of Milas to east of Karpuzlu and includes important albite occurrences such as Kutay, Alakaya, Sarıkaya, Yassıtaş, Yumrutaş., Söbçayırı, Sarıkısık, Sarpdere, and Gökkaya deposits (Fig. 2).

The structural unconformity between the roughly E-W trending tectonic elements of the "cover schists" in the south and NNE-SSW trending ones of the."core" in the Çine Submassif is variably interpreted as disconformity (Şengör et al., 1984), a shear zone (Bozkurt et al., 1993), an intrusive contact (Erdoğan and Güngör, 1996) or a detachment fault. According to the authors' field observations, it is important to note that the albite occurrences are restricted only to the "core", although locally, both marginal mylonitic zones and intrusive contacts are observed between the "core" and "cover" units. Although local tectonic control may cause deformation of albite veins within shear planes or transversal/oblique fracture systems that are more or less perpendicular to main alignment or even formation of S-type folds at the margins of the mega-shear zones,it is certain that albite occurrences are mostly of intrusive character and align parallel to the dominating NNE-SSW structural trend in the study area.

The geological map of the Karadere region, prepared by the field studies and aerial photographs, includes all the important quarries and is presented in Figure 3. Distribution of the albite deposits in this part is also well conformable with NNE-SSW trending orientation of the main tectonic elements.

The albite deposits in the outcrops and within the quarries are observed as vein-type elongated masses. The width of the veins can vary from 2-3 m to 30-40 m. Although the length of the albite-veins are controlled by some faults and some gneissic enclaves, it reaches up to 600 m in Söbçayırı quarry and 1000 m as in Karadere vein. The margins of the deposits are generally marked by meta-granitic wall rocks with high angle contacts.

Except the NNE-SSW trending main albite veins, deposits nearly vertical or oblique to these veins are also present. For example, Asar tepe and Kocayer deposits are situated within a nearly E-W oriented fault system.

Locally, the albite bearing veins may have long extensions along their dip directions. For example, in the Söbçayırı quarry, the difference between basal elevation and the ore at the top of the quarry is 120 m. Moreover, a drill hole at the base of the quarry intercepted 85 m albite ore, indicating that the veins may have extensions down to 200 m.

In terms of reserve, the main albite deposits (e.g. Çukuroluk and Yanıktepe quarries in Çallı group) are formed within the void-spaces at the junctions of two main fault systems. Other albite deposits (e.g. Erendede quarry) seem to be small-scaled laccoliths or fillings along the axial closure of a recumbent anticline are also present.

All these observations, suggest that the aplite and pegmatites of the Pan-African granitic complex in Çine submassif were replaced by the present "albitites" as a result of anatexis, rejuvenation and metasomatism processes in the period of alpine deformation and metamorphism.

MINERALOGY OF THE ALBITE DEPOSITS

"Each feldspar is different, if it is not, it is not a feldspar"

Mineralogical differences in the albitites of the Çine Submassif can be well explained with the above phrase of F. Laves which is at the beginning of the chapter on "Feldspars" in Tröger (1969).

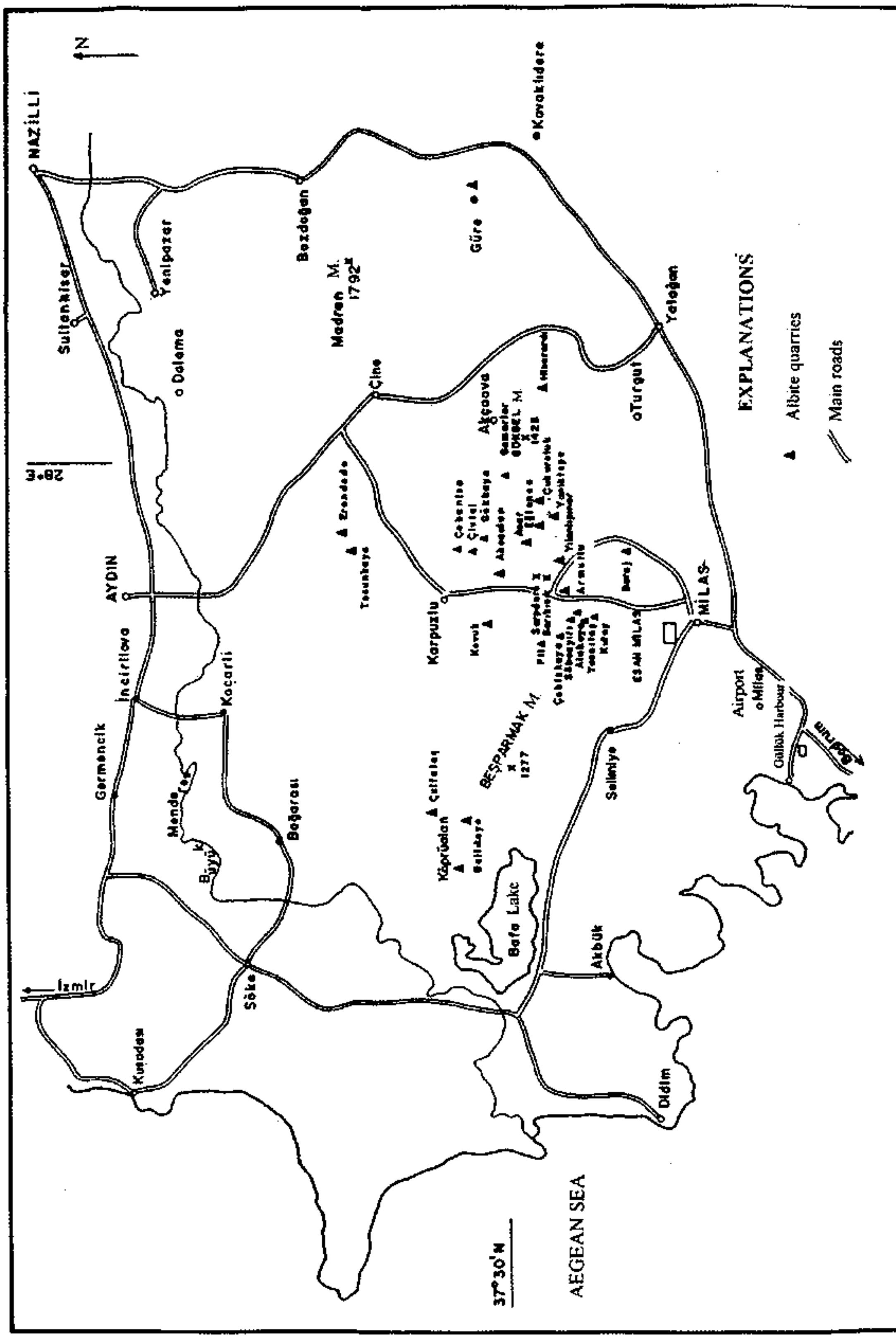

Fig. 2- Distribution of the albite deposits of Esan in the Milas-Çine region (SW-Turkey).

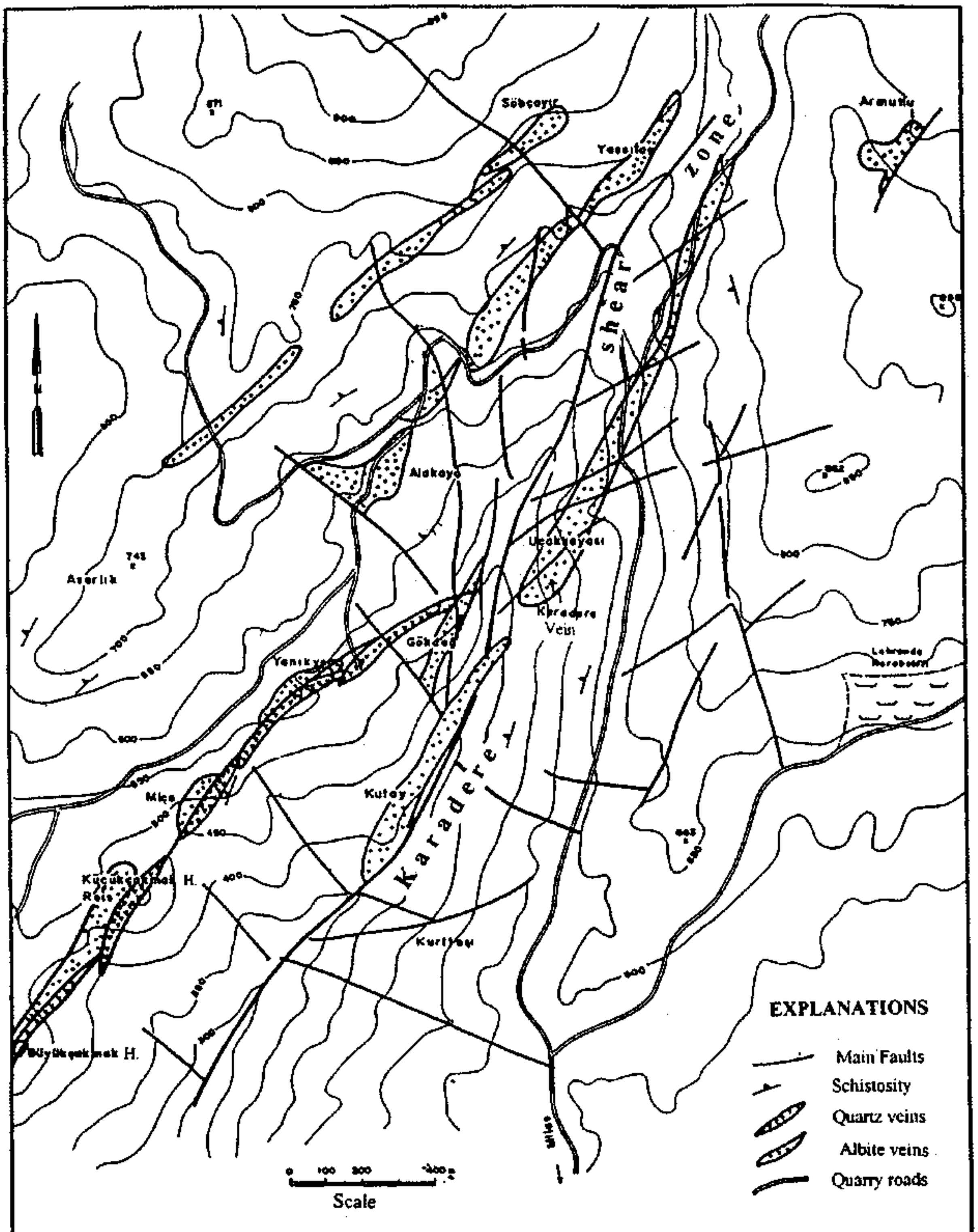

Fig. 3- Geological sketch-map of the Karadere shear zone and the distribution of the albite deposits.

Field observations, microscope studies, XRD and chemical analysis carried out on the aibitites shows that the main mineral phases are albite and quartz. The Na_2O content of the bulk rock samples varies between 7-11 % in some, of the albite veins, whereas the modal analysis of the samples display maximum albite contents about 70 %, and quartz 25 %.

Albitites typically display blastomylonitic textures. Two different generations of albite are observed; a- coarse grained (~1 mm) the first generation albites representing relict magmatic phenocrystals with deformed and broken polysynthetic twining, and b- finer grained (100-300 m) second generation albites that are developed as a mosaic along the margins of primary phenocrystalls and have no twinning. In addition to the primary coarse quartz grains (0.5 mm average length), there are finer grained elongated fresh quartz grains of second generation, that surround the primary albite phenocrystalls (mortar texture) together with secondary albite, or fill up the fractures and hail the fractured portions of the porphyroclasts.

The other main mineral in the samples is perthitic alkali feldspar. It also resembles the primary magmatic porphyroclasts, is relatively coarse-grained (above 1 mm) and can be found as in the form of microperthite or filmperthite, rarely leuco- or cryptocrystalline perthite. Locally preserved microclines are also noticed from the samples taken from the Erendede quarry. In some samples, the amount of the perthitic alkali feldspar can reach up to 40 % of the whole rock. Consequently, the K_2O ratio in these rock samples is relatively high. For example, in the Söke-Yeşilköy-Köprüalan quarry, the K_2O amount of the bulk sample changes between 0.4 - 7.0 % and a special product (code E-22) with an average of 3 % K_2O and 8 % Na_2O is obtained from this deposit. In also Ballıkaya deposits, where perthite crystals reaching to 1.5 cm are observed the K_2O or Na_2O contents reach up to 5-7 %.

In terms of CaO content, the highest value detected is 2.13 % in an albite vein at Eğlencederesi. However, this value does not exceed the albite-oligoclase boundary in modal analysis.

Apart form these three main minerals, other phases observed under the microscope are mica (muscovite, biotite), rutile, titanite, zircon, apatite and rarely chlorite. Although, tourmaline, garnet and epidote are present in the wall rock, but they are not present in the albite veins.

Biotites are present in the form of yellowish-brown colored sheets, sometimes with rutile or zircon inclusions. The first phase biotites (niagmatic) are intensely deformed, recrystallized and chloritized at grain boundaries. As it directly controls the color of the product, the presence of biotite is a normally a negative factor for the quality of the albite. However, it could easily be removed by magnetic separation and flotation. It's presence may even turn to an advantage, as most of the rutile (another negative agent for the color of the product) is enclosed in biotite (e.g. aibitites of the Asar tepe quarry) and can be also easily removed from the system during mineral separation and flotation.

Muscovite is generally secondary and is in the form of thin, long lepidoblasts, that are formed along shear or schistosity planes. Very small (< 50 m) muscovite crystals are sometimes scattered within the cleavage planes of some of the albite grains (e.g. Kocayer and Eğlencederesi veins) and indicates the presence of two different albite generations in the rock. According to Göncüoğlu (1997, written communication) the "ghost" orientation that is also discerned in muscovites as in the second generation albites and quartz show that the deformation continued during recrystallization process. Moreover, the presence of shear planes that cut this "ghost" orientation is indicative for another late-stage brittle deformation phase postponing the main deformation/recrystallization event. The occurrence of muscovite can be partly related to the removal of K from K-feldspars during metasomatism.

Secondary chlorite rarely develops after biotite. However, the formation of secondary Mg-chlorite may have a positive effect for the albite products, as it can the originally unsuitable colors during the smelting. This is the case with the Güre albite deposits to the east of Cine. The presence of secondary Mg-chlorite within albites of Sardine Island of Italy is also described by Bornioli et al., (1995).

The most important components determining the commercial quality of albite are Ti minerals that directly effecting the firing color. The TiO_2 content within the "extra albite" is less than 0.13 %, and it is more than 0.25 % within the ordinary products that are qualified as "standard albite". The studied albites used for the flotation process contain TiO_2 values that range between 0.13 and 0.25 % and they are processed according to the grain size of the Ti-mineral (300 or 500m).

The Ti-minerals in the samples are mostly rutile, and sometimes titanite. Generally, the length of the prismatic rutile crystals ranges between 0.1 - 0.3 mm and rarely exceeds 0.8 mm. Rutile, together with apatite, is mainly concentrated in the recrystallized part of the rock and is found together with fine grained albite and quartz between coarser porphyroclasts. As in the samples from the Erendede quarry, rutile grains sometimes do not negatively effect the smelting color very much, as they are found as tiny inclusions within the quartz grains. On the other hand, rutile together with zircon and apatite is concentrated along the gneiss and the albite vein boundaries (e.g. Armutdüzü, Sarıkısık, and Sarpdere to the north of Armutdüzü quarries), and in zones within the albitites, where the TiO_2 content reaches up to 7-8 %. These concentrations may be due to pegmatitic zonation or can also be evaluated as relicts of the metasomatism process. However, according to the recent observations these zones may also represent partly assimilated meta-sandstone enclaves with high heavy mineral contents. Transformation to titanite by metasomatism or formation of leucoxens as a result of alteration of rutile can be observed locally, however, in contrast to rutile, these secondary minerals do not effect the firing color of the product.

In addition to the primary rutile of pegmatitic - pneumatolytic (?) origin, zircon is in the form of very fine grains (> 0.1 mm), and apatite is in the form of hypidiomorphic crystals of 0.1 - 0.5 mm. The apatite content may locally exceed 3% (e.g. Yanıktepe quarry). Göncüoğlu (1997, written communication) differentiated two different zircon generations in the samples from Yassıtaş vein: An earlier, rounded and metamict one of xenolitic origin and a later idiomorphic, and transparent one directly crystallized from a melt.

In the Eğlencederesi vein, the occurrence with about 1 % calcite is the only accessory carbonate mineralization observed in albite deposits in the region. The other observed accessory minerals are arsenopyrite, pyrite, and hematite in the Armutludüzü quarry. This secondary mineralization contains up to 5 ppm gold.

CHEMICAL PROPERTIES OF THE ALBITE PRODUCTS

In the previous chapters, it was mentioned that albite exploited from the quarries were divided in to 3 main types as "standard" "extra" and "floated". Apart form the main minerals, accessories such as perthite, titanite and their grain size are very important for the quality of the product and for its usage.

For this purpose, some standards including 9 product types have been developed for albite ores produced at Milas-Çine region by Esan. Chemical constituents for these albite products are summarized as follows:

The products of E-series are raw ores, and are named as E-10 standart, E21-medium, E-30 super, E40 super extra. E-22 is a product that contains perthitic feldspars with both alkalies. GG and FG are floated, 300 m sized ores, and are called as "glass" and "transparent frit" quality, respectively. SG and CG are the E-10 and E-30 qualities, grinded to 63 m.

Table 1- Chemical properties of the albite products.

	E-10	E-21	E-22	E-30	E-40	GG	FG	SG	CG
SiO_2	70.41	70.74	68.40	70.15	70.32	70.86	70.60	70.74	70.15
Al_2O_3	17.75	17.92	18.35	17.90	18.10	17.90	18.30	17.92	17.90
Fe_2O_3	0.14	0.08	0.08	0.08	0.07	0.04	0.04	0.08	0.08
TiO_2	0.30	0.16	0.30	0.12	0.10	0.05	0.06	0.26	0.12
CaO	0.75	0.50	0.39	0.90	0.50	0.25	0.30	0.50	0.90
MgO	0.15	0.20	0.31	0.10	0.20	0.30	0.10	0.20	0.10
K_2O	0.40	0.40	3.32	0.40	0.40	0.30	0.30	0.40	0.40
Na_2O	9.50	9.50	8.18	9.75	9.82	10.00	10.00	9.50	9.75
AK	0.60	0.50	0.50	0.60	0.50	0.30	0.30	0.50	0.60

RESULTS

The Çine Submassif is a Pan-African-Precambrian ortho/paragneiss complex, and includes 10 concentric or radial intrusive dome structures that can be differentiated on the satellite images. According to the field and petrological data it is suggested that the albite deposits along NNE-SSW trending tectonic zones in the Çine Submassif are primary aplites and pegmatites of the granitic core rocks. However, generation of the albites is not a simple process and it must include different stages such as anatexis, rejuvenation and metasomatism related with the main metamorphic event during the alpine deformation.

Mineralogically the albite deposits also include two different generations of albite and quartz. Especially, the primary (magmatic) perthitic feldspars were deformed and altered during metamorphism and metasomatism, respectively. The formation of secondary albite and quartz hailed the deformational fabrics. In the albites of Sardine Island of Italy, it is known that K-feldspars and plagioclases are replaced by hydrothermal albite and quartz during metasomatism (Benedusi and Bornioli, 1997).

That no albite occurrences are reported from the northern part of the Menderes Massif but only in the south may depend on the alkaline character of the orthogneisses in the Çine Submassif as well as on a late alkaline-metasomatism related to the alpine rejuvenation of the core rocks. Some other veins within the same tectonic system (at Gökbeldağ and around Madrandağ regions) with small size K-feldspars with tourmaline and long quartz grains may be interpreted as hydrothermal in origin.

In addition to the petrological studies of the albites and different intrusive bodies in the Çine Submassif, the study of these occurrences by geochemical methods may help to interpret their geneses and to discover new deposits.

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