Mineral Res. Expl. Bull., 141, 27-52, 2010

APATITE-BEARING MAGNETITE DEPOSIT OF PINARBAŞI (ADIYAMAN); GEOLOGICAL, GEOCHEMICAL PROPERTIES AND ECONOMICAL POTENTIAL

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ABSTRACT.- In the near vicinity of the apatitebearing magnetite deposit of Pınarbaşı Permianaged Malatya Metamorphites consisting of, from bottom to top, chlorite schists, cericite schists, calcschists and recrystallized limestones cover large areas. These folded and faulted metamorphic rocks, which thrust over the Eoceneaged Maden Complex, underwent one regional metamorphism and one subsequent retrograde metamorphism in the greenschist facies. Mineralizations associated with chloritesericite schists are in the form of magnetitebearing apatite lenses. The ore horizons, which reach a thickness of 15 m and have a northsouth strike, dip approximately 30 degrees to the west. In the field, massive, banded and disseminated ore types are distinguished. The most important ore mineral is magnetite. It is followed by hematite, siderite, goethite and specularite. The proportion of the fluorapatite, the most valuable gangue mineral, reaches up to 30% in some places. Quartz, calcite, chlorite and sericite are other common gangue minerals. Rarely, rutile, zircon, monazite and xenotime are also observed. There is a significant positive correlation between Fe, P_2O_5 and depth. The variograms reveal holeeffects which reflect orerock alternations. Frequency distributions of the elements are logarithmic. Magnetite reserves with an iron content of over 20% Fe are approximately 78 Mt. The average P_2O_5 concentration of these reserves having an average Fe tenor of 35% is 1.57%. The F concentration of 3.46% in apatite is significant. However, rare earth element (REE) concentration of apatite (900 ppm) and V concentration of magnetite (800 ppm) are low. This deposit defined as classic Kirunatype sedimentary apatitebearing magnetite deposit, is not considered to be economically mined.

Key words: Pınarbaşı, magnetite, apatite, geochemistry and metamorphism.

INTRODUCTION

Iron deposits are considerably miscellaneous in nature with regard to both origin and structure. Apatite-bearing magnetite deposits constitute an important mineralization type of iron, which can form any kind of deposits. Deposits of this type, like Pınarbaşı Apatite-bearing Magnetite Deposit have great economical importance, which constitute the most important source of the Swedish steel industry, and are termed as "Kiruna-type iron deposits" in the literature (Wright, 1986). Other important apatite-bearing magnetite deposits are Cerro de Mercado (Mexico), El Laco (Chile) and Bafq (Iran) (Mücke and Younessi, 1994; Förster and Jafarzadeh, 1994). Examples of these deposits in Turkey are Avnik (Bingöl) and Ünaldı (Bitlis) apatite-bearing magnetite deposits.

Pınarbaşı apatite-bearing magnetite deposit is located approximately 6 km to the west of Çelikhan County of Adıyaman Province. The study area is easily accessible by an asphalt road of 30 km from Sürgü Subdistrict, located on Malatya-Gaziantep Highway (Figure 1).

PREVIOUS WORKS

There are numerous researches regarding various disciplines of geology on the deposit area and the near vicinity. The pioneer researchers are Tolun (1955) and Koşal (1967).

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They are followed by Perinçek (1979), Gözübol and Önal (1986), Önal et al. (1986), Yazgan and Chessex (1991) and Önal and Gözübol (1992). Iron and phosphorous contents, reserves and mineability subjects were studied by Öztürk (1982), Akar (1983), Büyükkıdık and Aras (1984) and Güneş (1994). Subsequent studies were performed by Önal et al. (2002) on the mineralogical nature and geochemical composition of the mineralization. Lastly, mineralogical and geochemical properties of the deposit were examined, radiometric age determination was performed and its economic potential was discussed by Çelebi et al. (2005).

The cuts and trenches observed in the study area prove that the widely outcropping Pınarbaşı apatite-bearing magnetite deposit has long been known and worked. Recent mining activities such as drilling works and ore heaps confirm that this area has been attracting interest since the middle of the 20th century. However some experimental works were performed in 1930s and 1990s, the high phosphorous content of the ores was not carried on (Çelebi et al., 2005).

Modern investigation studies were started in 1970 by MTA (General Directorate of Mineral Research and Exploration). During mapping, drilling and enrichment works, which were intermittently continued up to 1984, 9 drill holes, 385 m^3 trenches, 347 cores and 145 point samples have been examined, the reserve of the deposit was calculated and the extension of the ore was partly determined (Büyükkıdık and Aras, 1984). As a result of these works a magnetite reserve of 69.2 million tons with 28.56 % Fe and 2.01 % P_2O_5 grade was calculated. Güneş (1994)

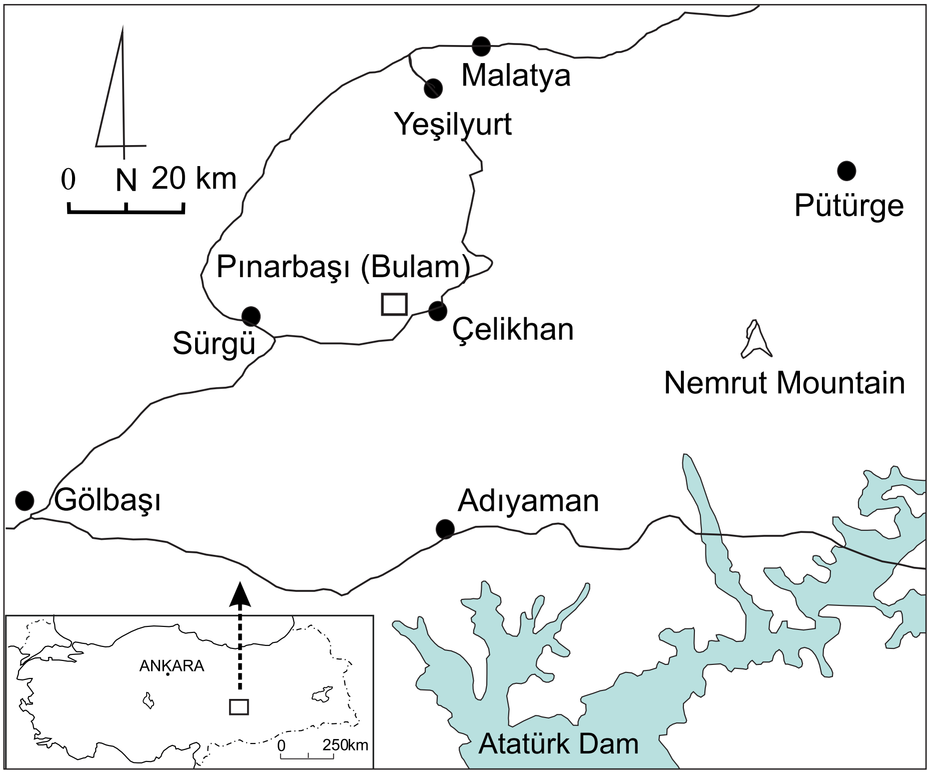


Figure 1 - Geographical location of the study area

declares 66.2 Mt (36.04 % Fe and 2.07 % P_2O_5) and Sıvacı et al. (2003) give 78 Mt (35.07 % Fe and 1.57 % P_2O_5).

SCOPE AND WORKING METHODS

The scope of this study is to investigate the geological structure and mineralogical properties of the Pınarbaşı deposit, macro and micro compositions of the ore and the wall rock, and to determine the economical significance of the deposit. For this purpose, the geology of the deposit and its near vicinity has been studied, and the nature, composition and potential of the mineralization were determined. In addition, fluorite and heavy element contents, which carry great importance for the production of vanadium and fluoric acid used especially in steel and battery production were analyzed, and the conditions of formation were interpreted by examining inter-elemental relationships and proportions.

GEOLOGICAL STRUCTURE

In the near vicinity of the Pınarbaşı apatite-bearing magnetite deposit, there are rock units of various age and origin. These are rock units of Paleozoic, Mesozoic, Tertiary and Quaternary ages (Figure 2) in which, the most important ones are: Paleozoic (Permo-Carboniferous) Pütürge and Malatya Metamorphites having wide distribution in the north of the collisional belt of Anatolian and Arabian Plates (Tolun, 1955; Perinçek, 1979), Eocene Maden Complex (Perinçek, 1979), and Quaternary alluviums.

STRATIGRAPHY

Pütürge Metamorphites constitute the lowermost unit of the area. Maden Complex, composed of volcano-sedimentary rocks, overlies this unit with an angular unconformity. Malatya Metamorphites, composed of schists and recrystallized limestones, thrust over this complex (Figure 2). At the top, Pliocene conglomerates and Quaternary alluvial sediments cover all these units with an unconformity.

Pütürge metamorphites

Pütürge Metamorphites are not observed in the deposit area and in its near vicinity. They are mainly exposed in the Pütürge district, the region which they were named. This unit, which is a product of regional metamorphism, presents greenschist facies conditions. From bottom to top, it is composed of gneiss, amphibolite schist, mica schist and recrystallized limestones. Pütürge Metamorphites is considered as the part of Bitlis Massif (Brinkman, 1971; Yılmaz and Yiğitbaş, 1990) and gained their present form in Eocene time. According to Önal et al. (1986), while the lower contact of the unit is not observed, the upper contact is angularly unconformable with Eocene Maden Complex composing of andesitic, spilitic tuffs, red mudstones and limestones (Figure 2).

Malatya Metamorphites

This unit is also called as "Kilkaya Limestone" and "Amanos Formation" by Gözübol and Önal (1986). Perinçek (1979) named it "Malatya Metamorphites" for its distinctive appearance in the south of Malatya and divided it into Lower and Upper Metamorphites. While took the unit into hand as Lower and Upper Units Gözübol and Önal (1986) examined this metamorphics by dividing into four units, from bottom to top, Pınarbaşı Formation, Koltik Limestone, Düzağaç Formation and Kalecik Limestones (Figure 2).

The Pınarbaşı apatite-bearing magnetite deposit takes place in the Malatya Metamorphites (Figure 3 and 5). Malatya Metamorphites thrust over Maden Complex and Pütürge Metamorphites. Gündüzbey Group of Upper Cretaceous which is represented by schists and recrystallized limestones as the products of intermediate and low-grade regional metamorphism (Önal and Gözübol, 1992), overlies this unit with an angular unconformity (Önal et al., 1986).

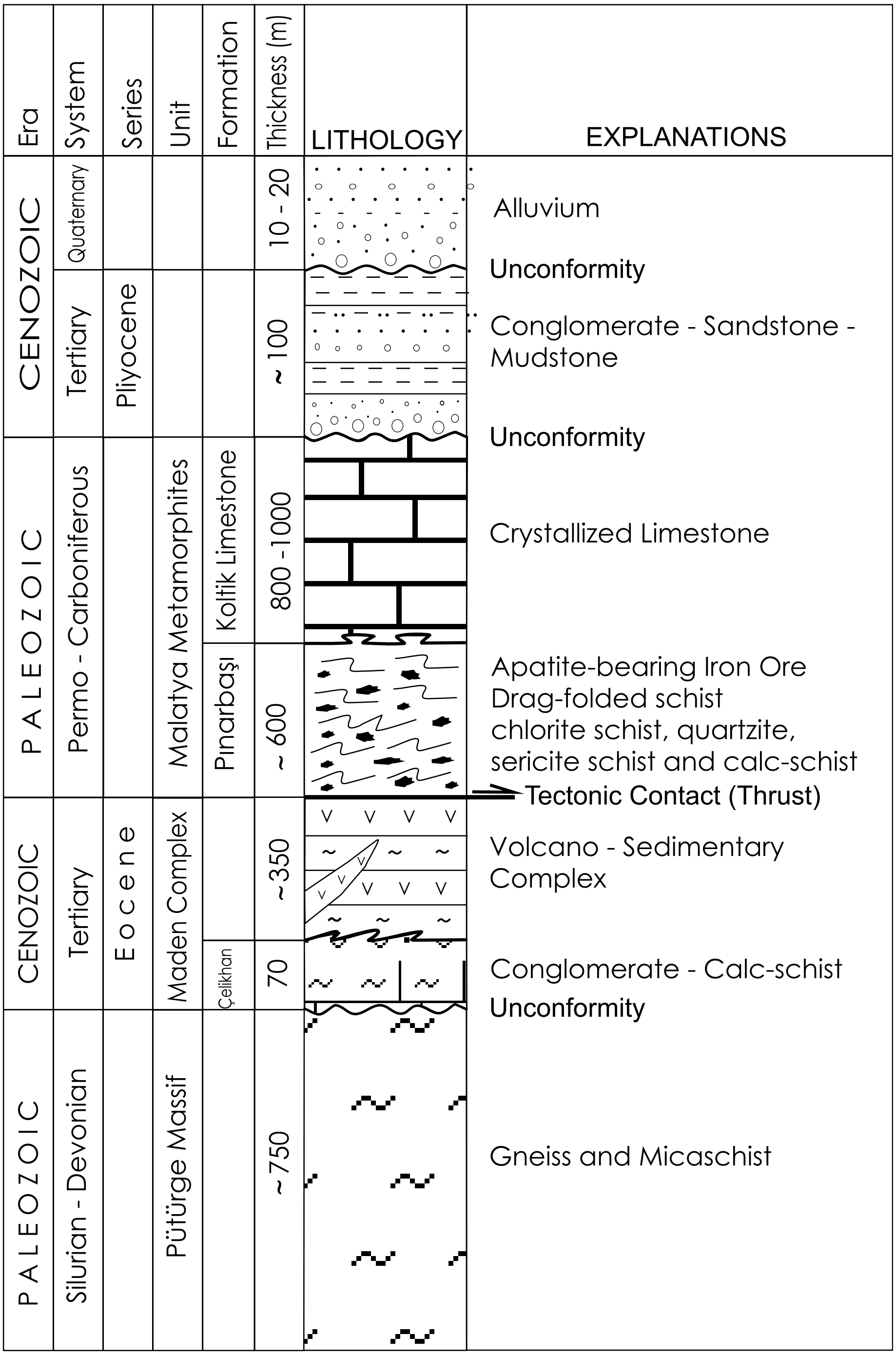


Figure 2- Generalized stratigraphic columnar section of Çelikhan District (Modified after Gözübol and Önal, 1986).

Figure 3 - Malatya Metamorphites observed in the north of Pınarbaşı Deposit. Ore-bearing schists of Pınarbaşı Formation (middle, dark), Koltik Limestones (up, light) and alluviums of Çelikhan Plain (front)

Pınarbaşı Formation is widespread in the north of the deposit. From bottom to top, the unit is composed of chlorite schists, sericite schists and calc-schists. Schistosity is well-developed in the unit. Abundant quartz veins in various thicknesses cross-cut the formation. Rarely, sulfites are also observed within these veins. Calc-schists, which are presented around the chlorite schists, are bituminous and dolomitic in places. Dolomitic parts are thick-bedded and fine-grained. Pınarbaşı mineralizations are mainly located in this unit (Figure 4).

Pınarbaşı Formation gradationally passes into Koltik Limestone. The thickness of this unit reaches up to 1000 m, and is widespread in the eastern part of the deposit. The lower parts of the unit are bedded and their color is dark gray and

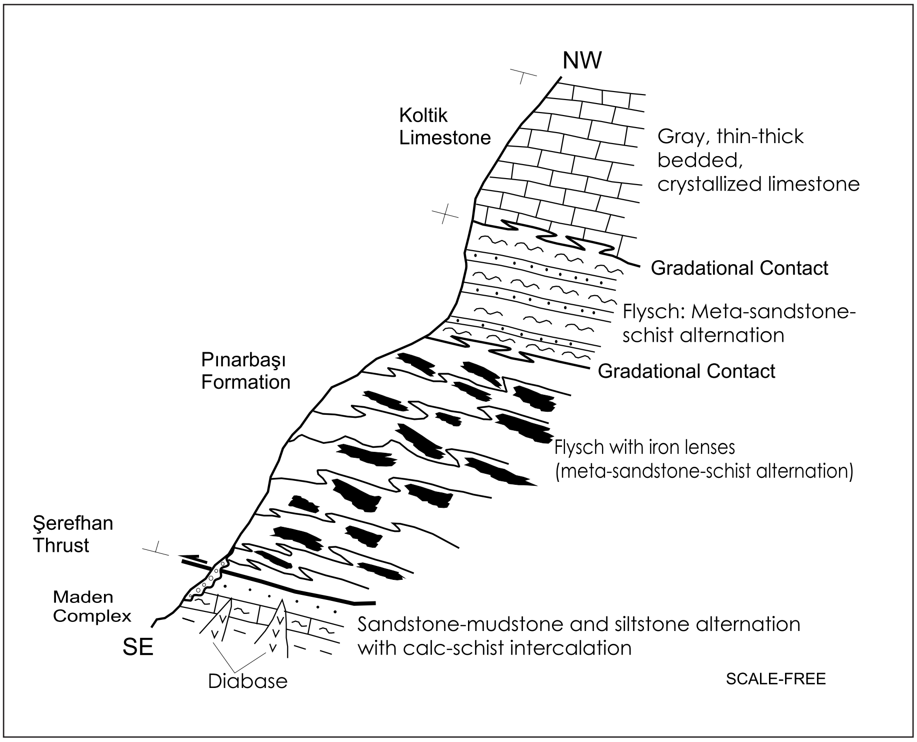


Figure 4 - Cross-section of Malatya Metamorphites at Çelikhan Hill, it explains Maden Complex and its relation with thrust line.

white. This recrystallized unit contains epidote, chlorite and quartz. Fractured limestones here are named Düzağaç Formation, and dolomitic limestones are named Kalecik Limestones by Önal and Gözübüyük (1992) and the age is given as Permo-Carboniferous according to their fossils. This unit does not exist in the deposit area.

MADEN COMPLEX

Maden Complex mainly consists of various colors limestones, sandstones, conglomerates and claystones. The unit includes andesites, diabases and spilitic basalts in the northeast of the district. This unit was named 'Maden' Complex by Perinçek (1979) because of it is observed best in the vicinity of 'Maden' County of Elazığ Province. The thickness of this unit reaches up to 350 m.

Maden Complex overlies Pütürge Metamorphites with an angular unconformity at the base (Önal et al., 1986). In the upper contact the unit is thrusted by Malatya Metamorphites. According to Gözübol and Önal (1986) it is probably of Lower Eocene age and was formed within an intracontinental basin.

INTRUSIVE ROCKS

Granitic and dacitic intrusions of various ages and compositions are observed in the region. The most important of these is a granitic intrusion observed in the south of Çelikhan. It formed a marked alteration zone around itself (Büyükkıdık and Aras, 1984). In addition, there are smaller intrusions formed on the thrust line, related to faulting. The ore minerals such as pyrite, malachite, azurite and chalcopyrite are observed within these intrusions.

QUATERNARY SEDIMENTS

In the valleys northeast and east of the study area, terraces and talus deposits are widely observed. The mineralizations in the deposit are largely covered by these talus deposits, the thickness of which reaches up to several meters (Figure 5).

TECTONICS

The most important structural elements of the study area are thrusts and folds. As the area is situated in the collision zone of the Taurides and the Arabian Platform, it was considerably affected by tectonic movements.

According to the field observations the most common tectonic element of the study area is Şerefhan thrust line which passes from the south of the Pınarbaşı Deposit. As a result of the collision of the Tauride Tectonic Belt with the Arabian Platform along this zone, Malatya Metamorphites moving westward, thrust over Maden Complex southward. As a result of this thrust, secondary thrusts and rock cleavages developed within the rock units.

Although in the north of the ore deposit a great number of folds, faults and dislocations are observed, they are not encountered in the south. Owing to north-south compression, folds and faults with north-south and east-west strikes developed. In the north of the area small-scale foldings developed within schists with anticline axis dipping to the south. As a result of these movements large recrystallized limestone blocks were driven into the schists (Figure 5) and thus caused foldings and faulting Önenç ve Yılmaz, 1981. Crystallized limestones are preserved in the west section of the anticline, whereas they are eroded in the east section. Tectonic structures consist of local folding, faulting and vertical faults. The ore is highly folded together with the schists, which indicates that the mineralization is older than the deformation.

METAMORPHISM

The rock units of the Pınarbaşı apatite-bearing magnetite deposit and its near vicinity under-

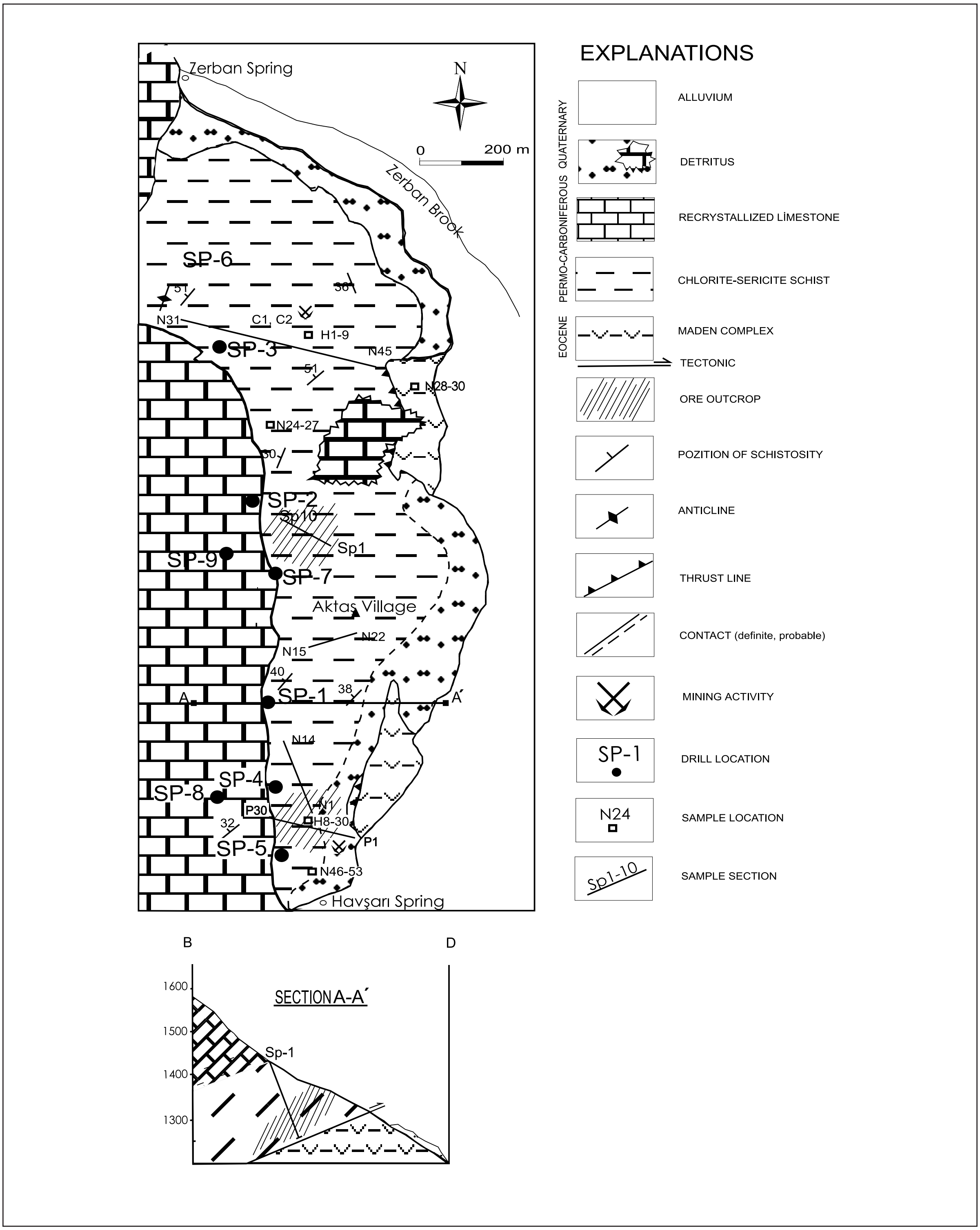


Figure 5 - Geological map of Pınarbaşı Deposit (Modified after Büyükkıdık and Aras, 1984).

went at least one regional metamorphism in the greenschist facies. According to microscopic examinations and diffractometric analysis, notable mineral association composed of chlorites (chlorite, chloritoid and sericite), micas (biotite and muscovite) and feldspars (albite) with epidote resulted from the grade of metamorphism has been determined (Çelebi and al., 2005). According to Winkler (1976) this mineral association corresponds to the quartz-albite-muscovite-chlorite subfacies of the greenschist facies of regional metamorphism. Index minerals determined here are shown in table 1 (Çelebi and al., 2005).

Rarely encountered biotite, epidote and garnet indicate that the mineralization in Pınarbaşı was able to reach, at most, the beginning of the quartz - albite - epidote - biotite subfacies. Brownlow (1996) states that this typical mineral association can only be the metamorphic product of the sediments of pelitic origin in the greenschist facies. The values obtained from ^{18}O isotope analyses showed that the formation temperature of the deposit ranges from 282 °C to 372 °C (Çelebi et al., 2005). This temperature corresponds to greenschist facies temperature of the metamorphism. Hydrogen isotope analysis give sedimentary rock values and support geochemical findings (Çelebi et al., 2005).

Radiometric age determination gave 66 and 48 Ma. Of these, the older (66Ma) reflects the metamorphism age realized by ophiolite development (Campanian) (Çelebi et al., 2005). And 48 Ma expresses the age of the second metamorphism, retrograde metamorphism or tectonic movements (Eocene) (Yazgan and Chessex, 1991; Aktaş and Robertson, 1984). According to these findings, the metamorphism in Pınarbaşı can be defined as weak regional metamorphism referring to the Winkler classification (1976), during which pressure was effective. The formation conditions of such a metamorphism approximately correspond to 400 °C temperature and 400 MPa pressure.

MINERALIZATION

Form of mineralization

The principal ore mineral of Pınarbaşı apatite-bearing magnetite deposit is magnetite. Apatite is present essentially as a gangue mineral together with quartz (Çelebi et al., 2005). According to field observations and drilling data, ore horizons which lie horizontally and consist of chlorite-sericite schist, magnetite and apatite alternation get deeper towards the south (Figure 6). These ore horizons, which concentrate in chlorite schists in the upper parts of the deposit, at various depths exist in the form of lenses or in tabular form. The mineralizations perpendicular to the north-south thrust direction dip to the west with an angle reaching partly to 70° (Figure 5, cross section A-A,) and grade laterally and

Table 1- Index minerals.

Facies	Subfacies	Index minerals
Greenschist facies	*Qu+Ab+Mu+Chl*	Chloritoid/chlorite Muscovite
	Qu+Ab+Ep+Bi	Biotite
	Qu+Ab+Ep+Alm	Epidote Almandine

Qu: Quartz, **Ab**: Albite, **Mu**: Muscovite, **Chl**: Chlorite, **Ep**: Epidote, **Bi**: Biotite and **Alm**: Almandine

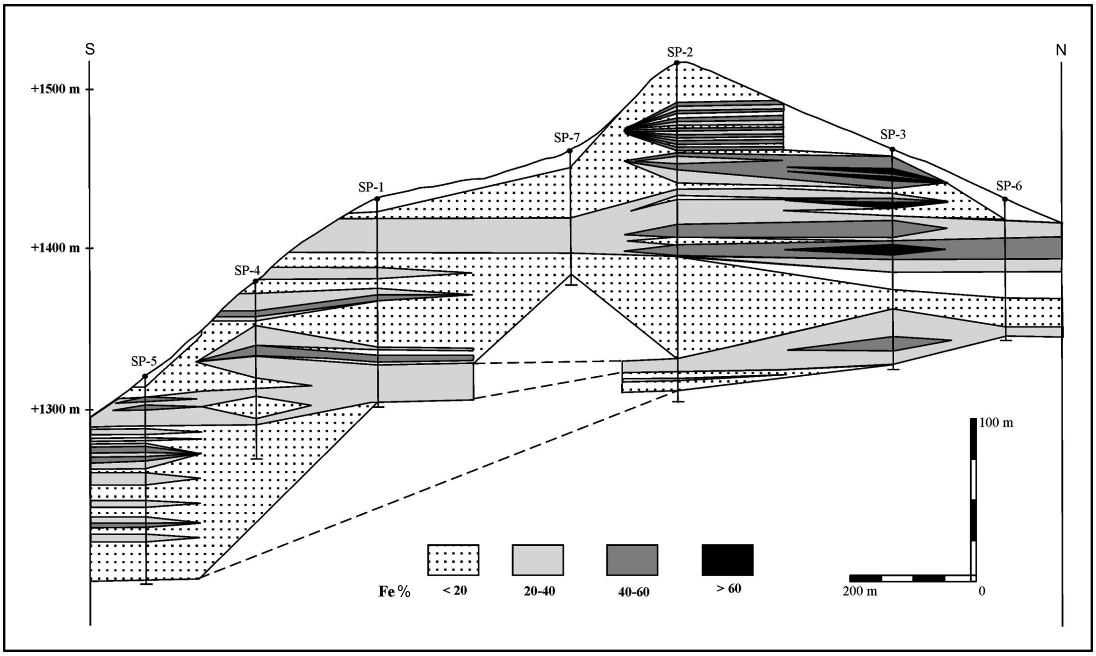


Figure 6 - Horizonal position of the ore zone in N-S direction, ore horizons go deeper southward (Çelebi et al, 2005; figure 5).

vertically into marbles (Büyükkıdık and Aras, 1984). The thicknesses of the ore lenses reach up to 15 m, and their lateral extension reaches up to several hundred meters (Figure 5 and 6). The total thickness of the ore zone reaches up to 100 m (for example, in drill hole SP-3). According to the data obtained from SP-8 and SP-9, the ore continues eastward below the recrystallized limestones and it can be traced up to a depth of 200 m alternating with the wall rock (Çelebi et al., 2005). At the surface, limonitization is observed.

Magnetite, which is found in massive, banded and disseminated form in Pınarbaşı apatite-bearing magnetite deposit, exhibits ore types of different structure and quality depending on the ratio of concentration. The most common ore mineral is magnetite. It is followed by hematite, goethite and very little amount of siderite.

Massive mineralization formed by the diminution of the wall rock in favor of the apatite and magnetite in the bulk volume remaining behind pure magnetite and apatite. The 'massive' concept here comprises ores with an iron content of over 50%. It is prevalent in the middle (drill hole SP-2) and northern (drill hole SP-3) parts of the deposit. It is denser in the upper horizons compared to the deeper ones. And this causes the iron content decrease with depth, as observed in SP-2 and SP-4. The thickness of the massive ore can reach 10 m as observed for example in SP-3 (Figure 6). Its lateral extent can be many times greater than its thickness.

Massive magnetite contains apatite and silicate only as bands and fine particles of mm dimensions. It displays conspicuous orientation. According to MTA's core and channel sample analyses, it is the ore type with the highest P_2O_5 content. This condition is best observed in drill hole SP-2. This determination reveals the existence of a positive correlation between apatite and magnetite.

Banded mineralization consists of the alternation of well-oriented magnetite, apatite and chlorite schist (Figure 7). This ore type, which is more conspicuously observed in the southern part of the deposit, can be of various depths and thicknesses. Most probably, during metamorphism, orientation occurred as a result of pressure. This is observed in all types of ore. The thickness of the bands can reach up to several cm varying with the grain size of the ore and gangue minerals. Banding is parallel to the schistosity. Laterally it passes into disseminated ores. In the magnetite content of this ore type large idiomorphic magnetite crystals are dominant, which the ratio is around 50%.

Disseminated mineralization is the most common ore type. It is observed all over the deposit in various concentrations and dimensions. This mineralization type is always associated with banded and massive mineralizations. However, the normative magnetite content of this ore, composed of magnetite and apatite crystals of millimetric size, often irregular and fine-grained, in parts idiomorphic and oriented parallel to the schistosity, does not exceed 30% (Figure 8). Consequently the recovery of this ore type during an operation is only possible if they were together with the massive and banded ores.

MINERALOGICAL EXAMINATIONS

Microscopic examinations reveal that the mineralogy of the Pınarbaşı deposit is quite simple. As mineral groups oxides (magnetite, hematite), silicates (mica and chlorites) and phosphates (apatite) are considerably prevalent (Çelebi et al., 2005). But this shows that the parent rocks of the deposit were not rich in all elements or the metamorphism did not reach the grade to constitute various mineral paragenesis. The existence of a marked orientation as a result of metamorphism is observed in ore and wall rocks. According to the results of the chemical analyses and optical and electron microscope observations, the wall rock consists of greenish-gray chlorite (chamosite, Fe-chlorite: $(Fe^{+2}, Mg, Fe^{+3})_5 Al(Si_3Al)O_{10} (OH,O)_8$) and gray (muscovite) and brown (biotite) mica minerals (Çelebi et al.,2005). By means of their fibrous structure, easily recognizable chlorites and flaky mica minerals are followed by quartz of various grain sizes. These three mineral groups are always associated with magnetite and apatite and often, as a result of the orientational forces of metamorphism, they are well-oriented or interrupted. Within the chlorite-schist texture composed of chlorite, sericite and quartz, a well-oriented, amorphous old magnetite and an idiomorphic secondary magnetite coexist (Figure 8). It is observed that the oriented, old magnetite is associated only with the chlorite schists and alternate with the wall rocks. Idiomorphic magnetites are not affected by deformation as they formed, most probably, after metamorphism, for example during retrograde metamorphism.

Figure 7- Banded magnetite (dark) alternating with chlorite schists (light).

Recrystallized limestones, which overlie chlorite - sericite unit with normal contact, are moderately stratified and oriented parallel to the schistosity. Recrystallized limestones, which are microscopically composed of calcite, in places show dolomitic composition. Idiomorphic calcite grains show granoblastic texture and twinning lamellas. Chlorite, mica, epidote and opaque minerals are rarely encountered associated with calcite.

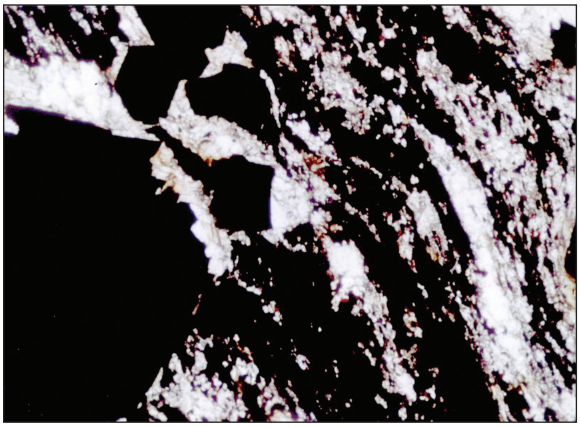


Figure 8 - Within well-oriented chlorite-sericite schist, alternating with quartz (white) and apatite old, amorphous and young, idiomorhic magnetite generations (black) are present together. Red parts are hematite.

According to ore microscopy examinations, magnetite exists in various forms in Pınarbaşı apatite-bearing magnetite deposit. Magnetite grains, which can reach only a grain size of less than 0.5 mm in rich or massive ore zones, can display a grain size reaching several mm in diameter in disseminated ores. Idiomorphic magnetite crystals are encountered especially in poorly oriented disseminated ores.

Microscopically, magnetite is of dark gray color, coarse-grained, mostly idiomorphic and present a martitization developed in two directions along crystal edges. Thus, the octahedral surfaces of the crystal grains can be clearly observed (Figure 9). It is observed that the martitization is more advanced in fractures and fissures. It is also seen that free magnetite grains are transformed partially or completely into hematite. This can be interpreted at the same time as a replacement. It is possible to see that this is advanced up to goetite in the magnetite grains at the surface. Magnetite can rarely accommodate minerals such as hematite, pyrite and gangue minerals such as apatite and chlorite as inclusions.

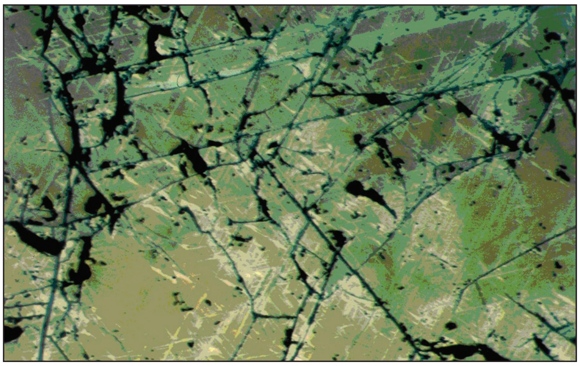


Figure 9 - Martitization, developed in two directions in magnetite crystal (idiomorphic and fractured). Brown indicates titanium, fractures indicate tectonics.

Hematite formed, most probably, totally as a secondary mineral from magnetite. Under microscope, it is distinguished by its light gray color. It is also rarely observed as inclusions in magnetite. It is not possible to distinguish original hematites from the ones which are the derivatives of magnetite. It is also possible to see that the magnetite, transformed into hematite at the surface, is transformed into goetite by decomposition. Together with iron oxide minerals, very small amount of rutile and some sulfite minerals such as pyrite and chalcopyrite in disseminated form are also observed.

In Pınarbaşı apatite-bearing magnetite deposit, along with magnetite and hematite, the most important mineral of economic importance is fluorapatite. In the field, with the naked eye, it can be distinguished from quartz by its grayish color, prismatic crystal form and brittle nature. Apatite generally occurs in disseminated or banded forms. Its color is gray and pink, and it is generally fine-grained (< 1mm). Apatite, identified by its gray rods with fractures and threads under the microscope, is primarily associated with chlorite, quartz and magnetite (Figure 10). Its proportion in the ore ranges between 3% and 5%. However, horizons containing over 25% apatite are encountered in rare cases. It is observed that it was affected by tectonism and-

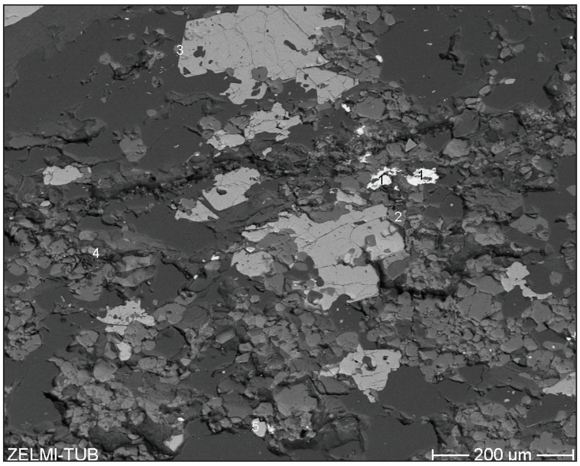


Figure 10- Magnetite with large crystals (light gray), monazite (1), rutile (2, 3, 4) and zircon (5) in a matrix composed of apatite (gray) and quartz (dark gray).

shows orientation with the wall rock. As a result of electron microscope examinations, rarely, some minerals such as hydroxylapatite, monazite, xenotime, and zircon were determined along with fluorapatite. Pink fluorescence color, low radioactivity (8-10 cps) and low content of trace elements (< % 1) are other important characteristics of Pınarbaşı apatites.

GEOCHEMISTRY

In Pınarbaşı apatite-bearing magnetite deposit, the method of taking representative samples was adopted. According to this method, as to form approximately perpendicular sections to the strike and dip of the ore, 154 pieces of representative samples weighing around 1 kg were taken (Figure 59). These samples consist of 107 ore samples and 47 wall-rock (Fe_2O_3<%20) samples taken from various parts of the deposit. When the study area was taken into consideration, approximately 80 samples were considered sufficient for a research of this range. Samples were taken from as fresh as possible ore or from the wall rock, and after being halved, they were ground (<100 µm) in chrome-carbide vessels. And then they were prepared for analysis.

Elemental analyses of the samples were carried out in the laboratory of Berlin Technical University, using rontgen fluorescence analysis apparatus (RFA). Percentages of the analyzed elements are given in Table 2. Ag, As, Bi, Br, Cl, Cu, Cs, Hg, Mo, Sb, Se, Sn, Tl, and W were not detected during the analyses. Cd, Cu, Ga, Sn and U are not in reliable concentrations. In parallel to these, analyses of gold, silver and platinum group elements (PGE) together with some important trace elements were performed by neutron activation method on 30 other samples (Çelebi et al., 2005). In these samples, Ag and PGEs were not detected. But, Au concentration reaching 1 ppm was detected. In addition, the values of MTA's approximately 287 drill core analyses were also examined for geostatistical evaluation.

Analyzed apatite-bearing magnetite samples of Pınarbaşı Deposit seem to be poor in minor and trace elements. The most marked characteristic of the analyses is that the samples contain high P_2O_5 (phosphate) along with moderate Fe_2O_3. On the other hand, their Alkali (Na and K) and S contents are low. It is seen that many trace elements, for example, Ba, Mn, Ni, Sr, V, Zn and Zr, have high concentrations (Table 2). Compared with Clarke value, the most enriched element is P (12-fold). It is followed by Fe (7-fold), V (3-fold) and F (3-fold). Although some siderophile minor and trace elements, such as Co, Mn, Ni and Ti maintained their Clarke level; some alkaline earth elements such as Ba and Sr became diluted.

The main components of the analyzed samples are: Fe (47.18% Fe_2O_3) coming from magnetite and Si (27.45 SiO_2) coming from quartz and silicates (chlorite and mica). The average content of P_2O, considered as a valuable raw material, is 3.01%. This percentage is as high as to negatively influence the exploitability of the iron (maximum 500 ppm P= 0.14% P_2O_5 is demanded for steel production). However, it is known that it is possible to separate it

Table 2- Analysis values of representative ore samples of Pınarbaşı (Bulam) Deposit and some important parameters

Line No	sample	SiO_2 %	TiO_2	Al_2O_3	Fe_2O_3[1]	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5	F[2]	SO_3	Ba ppm	Co	Cr	Ni	Pb	Rb	Sr	Th	V	Zn	Zr	H_2O[3]	CO_2[3]	Total
1	SP-2	21,10	0,29	7,18	53,82	0,66	1,37	0,60	0,34	0,23	1,69		0,03	100		131	162	84		215	4	524	221	277			87,31
2	SP-3	22,05	0,32	8,82	56,06	1,84	1,67	0,46	0,24	0,26	1,91			61	2	111	136	53		165	10	664	270	316	0,16	4,04	97,83
3	SP-4	22,26	0,31	10,18	56,86	1,10	2,83	1,12	0,21	0,19	2,99		0,02	66		168	186	90		320	4	741	238	347			98,07
4	SP-5	35,90	0,53	7,66	40,62	0,78	4,46	0,47	0,17	0,18	4,32	0,34		125	40	27	76	62	9	241	2	189	178	299	0,13	2,99	98,55
5	SP-6	20,73	0,26	7,75	51,58	0,28	8,60	0,41	1,29	0,06	7,69	0,16	0,10	381		91	49	24	43	387	13	699	33	185			98,91
6	SP-7	20,98	0,45	11,34	51,38	0,85	2,17	0,08	0,02	0,50	2,37	0,31	0,03	76	24	46	82	76		67		564	206	153	0,35	6,57	97,40
7	SP-8	16,42	0,23	9,04	52,03	0,29	8,89	0,51	1,24	0,01	8,22	0,01		136		161	50	67	30	414	5	903	45	201			96,89
8	SP-9	20,12	0,28	10,01	55,28	0,38	6,93	0,57	1,66	0,02	6,64			159		136	56	67	47	330	5	904	43	211		0,24	102,13
9	SP-11	38,66	0,38	13,96	30,99	2,50	4,95	0,33	3,44	0,28	0,22	0,17	0,07	682	16		32	12	111	233	8	154	120	76			95,95
10	SP-12	41,55	0,35	12,66	31,38	2,74	4,36	1,82	2,03	0,21	0,21	0,12	0,04	566	16	9	36		65	260	7	106	84	95			97,47
11	N-1	58,46	0,61	12,86	17,89	0,43	0,85	0,10	0,06	0,05	0,79	0,15	0,05	30	13	136	34		10	20	11	117	58	404	0,18	3,78	96,26
12	N-2	10,40	0,40	8,68	66,56	0,74	3,86	0,10	0,20	0,93	3,43	0,01	0,48	248	101	144	205		23	437	10	934	329	436	0,14	3,18	99,13
13	N-3	56,02	0,98	19,24	14,38	0,32	0,40	0,26	2,40	0,07	0,31	0,13	0,05	337	15	160	28	40	54	26	20	92	124	713	0,06	2,57	97,19
14	N-4	26,95	0,52	8,87	48,76	0,62	3,69	0,10	0,04	0,71	2,93	0,20	0,08	81	43	125	66	26	10	164	21	384	158	185	0,28	4,80	98,55
15	N-6	49,37	1,10	24,95	15,24	0,49	0,13	1,20	3,02	0,05	0,10	0,01	0,05	355	10	521	110	92	108	271	14	159	116	226	0,05	4,24	100,00
16	N-8	17,08	0,32	9,73	61,37	0,30	4,00	0,27	1,53	0,18	2,87	0,01	0,12	352	17	116	90	27	67	469	18	503	110	232	0,12	1,20	99,10
17	N-9	14,73	0,40	8,90	65,53	0,30	3,24	0,10	0,67	0,41	2,42	0,01	0,13	401	66	149	153	15	39	345	22	480	164	308	0,16	2,69	99,68
18	N-15	17,44	0,45	9,65	61,25	0,30	4,77	0,40	1,34	0,10	3,18	0,01	0,08	197	15	107	65	30	59	437	25	441	88	262	0,07	0,05	99,10
19	N-17	31,87	0,49	14,67	39,22	0,35	1,17	0,17	2,20	0,11	0,90	0,24	0,06	279	28	151	77		79	28	16	339	121	607	0,12	6,63	98,20
20	N-21	13,89	0,24	11,92	64,00	0,30	2,35	0,77	1,38	0,15	1,86	0,08	0,24	434	10	68	36		94	166	10	799	106	176	0,06	1,44	98,68
21	N-22	17,04	0,67	11,31	61,37	0,30	2,95	0,10	0,06	0,25	2,42	0,17	0,06	55	32	173	74			46	13	344	126	157	0,07	2,59	99,36
22	N-24	15,75	0,47	10,00	61,03	1,60	2,90	0,10	0,07	0,32	2,07	0,20	0,08	102	29	115	95	19		69	19	495	169	164	0,16	4,21	98,96
23	N-27	48,55	0,71	15,35	27,45	0,56	0,75	0,10	0,06	0,10	0,77	0,19	0,05	30	46	200	81			44	10	143	172	326	0,13	4,68	99,45
24	N-32	23,56	0,58	12,04	47,16	0,30	3,71	0,10	0,48	0,34	2,89	0,35	0,06	101	25	195	70		17	59	11	413	161	285	0,13	6,91	98,62
25	N-39	26,22	0,25	8,94	49,07	0,30	5,52	0,27	0,95	0,14	5,03	0,18	0,09	207	10	112	29		43	386		386	40	148	0,13	1,77	98,86
26	N-40	46,77	0,41	8,59	34,70	0,33	1,59	0,10	0,15	0,06	1,34	0,22	0,05	109	24	155	54		10	105		217	60	212	0,17	4,22	98,70
27	N-44	8,04	0,27	7,49	67,40	0,30	7,08	0,45	1,48	0,02	5,97	0,64	0,27	227	10	98	37		78	361		861	40	197	0,04	0,36	99,81
28	N-47	49,57	0,86	18,55	23,20	1,78	0,33	0,17	0,42	0,12	0,27	0,14	0,05	79	12	189	59		11	13	18	142	184	321	0,06	3,39	98,91
29	P-13	26,03	0,26	9,35	53,03	0,30	3,87	0,21	0,57	0,23	2,64	0,01	0,07	261	18	140	91		24	201		249	112	167	0,11	0,49	97,17
30	P-22	3,62	0,35	8,22	64,36	0,30	10,51	0,80	1,55	0,02	8,36	0,74	0,25	298	10	230	124		72	461		843	45	227	0,05	0,06	99,19
31	P-23	29,92	0,34	9,34	39,66	0,40	10,24	0,22	1,41	0,08	6,62	0,30	0,05	285	13	156	49		42	237		182	40	121	0,07	0,55	99,20
	$\overline{x}$ =	27,45	0,45	11,20	47,15	0,71	3,88	0,40	0,99	0,21	3,01	0,19	0,10	234	25	152	72	43	50	217	14	429	116	254	0,12	2,90	
	s =	±14,61	0,22	3,95	15,94	0,67	2,87	0,40	0,94	0,21	2,46	0,18	0,10	165	21	91	41	28	32	160	6	284	67	148	0,08	2,18	
	v =	53	48	35	34	95	74	99	95	100	81	95	99	71	84	60	57	65	64	74	43	66	57	58			
	c =	27,72	0,44	8,13	5,00	2,09	3,63	2,83	2,59	0,10	0,11	0,06	0,03	425	25	55	90	13	90	375	7	135	70	165			
	$\overline{x}$ **/c** =	0,46	0,62	0,73	6,70	0,20	0,76	0,11	0,32	1,67	12,35	3,02	1,54	0,55	1,01	2,76	0,80	3,29	0,55	0,58	1,91	3,18	1,66	1,54			

1 Total iron oxide 2 No void cell or value too low 3 Not analyzed in all samples

$\overline{x}$: Arithmetic mean, s: Standard deviation, v: Variation coefficient (= s.100/ $\overline{x}$), c: Clarke value (Mason and Moore, 1985), $\overline{x}$ / c: Enrichment ($\overline{x}$ / c >1) or dilution ($\overline{x}$ / c <1)

(Pfeufer, 1997; Ranjbar, 2002; Wellenkampf and Souzo, 2002). The most regular distribution is displayed by Fe_2O_3 and Al_2O_3 (coefficient of variation v = standard deviation x 100 / arithmetic mean= 34 % and 35%). All the other components are considerably variable (v>80). These characteristics mean that this deposit possesses a heterogeneous mineralization and that during a possible operation, it will be difficult to reach a definite average tenor. According to the obtained values of the sample analyses, geochemical data give clues peculiar to sedimentary rocks in the origin of mineralization. These can be enumerated as:

- Positive Al_2O_3-K_2O and Al_2O_3-Ba correlations (Table 3). This shows that these elements are bound to clay minerals. High contents of Al, Ba and Rb and higher percentage of K compared to Na (K/ Na = 2.83, Table 2) and poor correlations between MgO, Cr, Ni, Co and SiO_2 and among themselves (Table 3) do not reflect a magmatic differentiation.

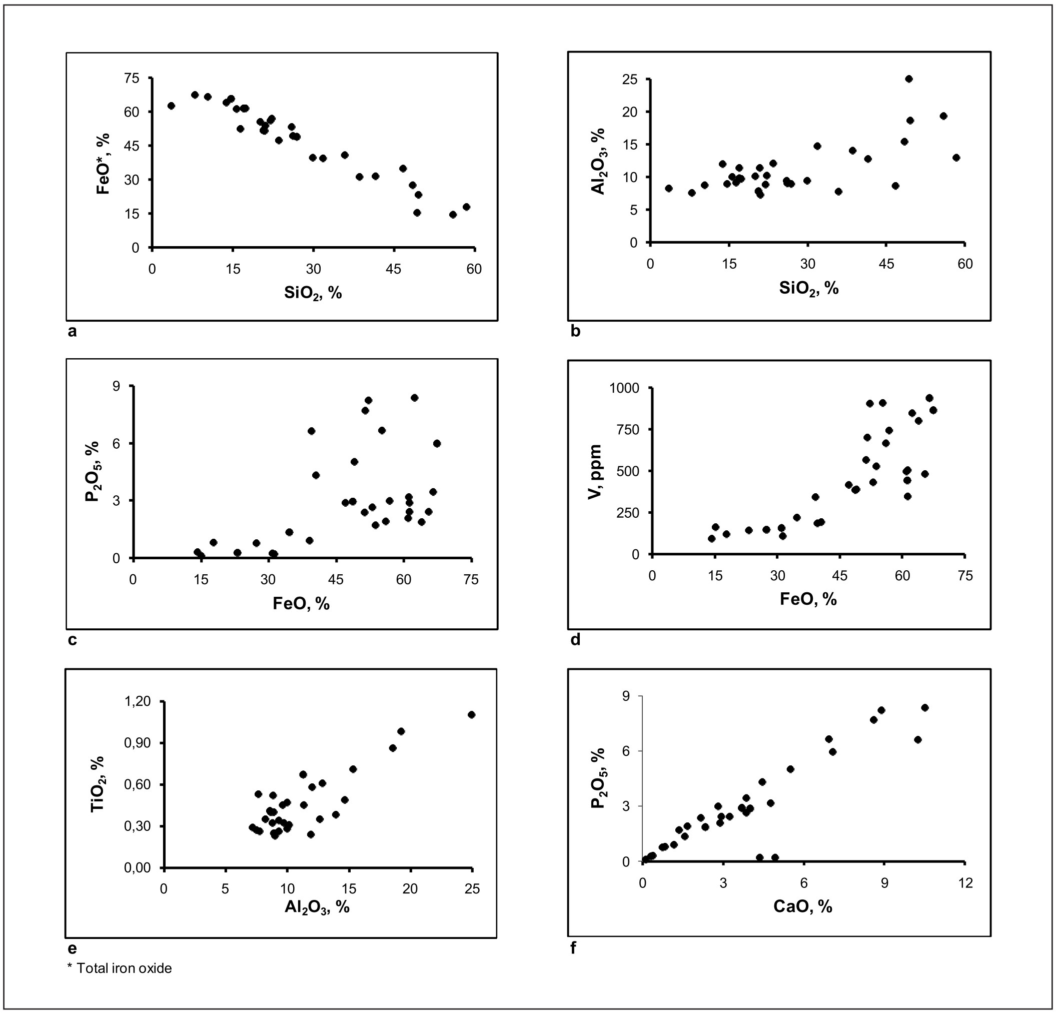
Criteria used to differentiate ortho-rocks from para-rocks are obtained from relations and ratios between certain pairs of elements which behave differently in magmatic and sedimentary environments. Reactions in sedimentary environments take place under higher conditions of oxidation compared to magmatic environment. Pressure and temperature are much lower in the sedimentary environment compared to magmatic environment. The inter-elemental correlations, ratios and Niggli values of the analyzed sample material associate a sedimentary origin. Some selected inter-elemental correlations are shown below.

Correlation analysis

a) *Values of whole rock analysis.*- There are significant positive and negative correlations between numerous components or elemental concentrations of the analyzed samples (Table 3). The important ones are shown in figure 11. The most significant negative correlation is observed between Fe_2O_3 and P_2O_5 (which constitute valuable raw materials) and silicate-forming SiO_2, Al_2O_3, main alkaline components and their trace elements. This means that Fe and P became concentrated and silicates and alkalis became diluted. For example, while Fe_2O_3 and SiO_2 display negative correlation, SiO_2 and Al_2O_3 concentration variations are positive (Figure 11 a, b). Furthermore, there is also a significant

Table 3- Correlation coefficients between components of Pınarbaşı ore samples. For sample number n= 31, positive correlation coefficient |r| >0,355 with 95% probability (dark: important coefficients)

SiO_2																		
0,658	**TiO_2**																	
0,673	**0,842**	**A_2O_3**																
-0,**968**	-0,690	-0,748	**Fe_2O_3**															
0,238	0,013	0,169	-0,238	**MgO**														
-0,544-	0,585	-0,550	0,430	-0,178	**CaO**													
0,016	-0,088	0,173	-0,081	0,367	0,121	**Na_2O**												
0,150	0,116	0,459	-0,295	0,131	0,210	0,424	**K_2O**											
-0,270	-0,048	-0,205	0,308	0,191	-0,184	-0,281	-0,383	**MnO**										
-0,613	-0,547	-0,601	**0,521**	-0,427	**0,903**	0,001	-0,022	-0,193	**P_2O_5**									
-0,238	-0,132	-0,270	0,154	-0,072	0,410	0,011	-0,044	-0,204	**0,417**	**F**								
-0,011	-0,145	0,177	-0,069	0,270	0,249	0,400	**0,798**	-0,058	-0,065	-0,161	**Ba**							
-0,209	0,003	-0,221	0,264	-0,115	-0,092	-0,342	-0,378	**0,749**	-0,005	-0,257	-0,095	**Co**						
0,254	**0,603**	**0,644**	-0,358	-0,245	-0,189	0,112	0,350	-0,184	-0,140	-0,085	-0,020	-0,069	**Cr**					
-0,380	-0,080	-0,188	0,409	0,016	-0,166	0,071	-0,345	0,485	-0,033	-0,116	-0,209	**0,644**	0,299	**Ni**				
-0,576	-0,530	-0,443	0,526	-0,170	**0,662**	0,342	0,267	-0,015	**0,636**	-0,020	0,355	0,129	-0,021	0,253	**Sr**			
-0,827	-0,593	-0,529	**0,785**	-0,247	0,458	0,094	-0,114	0,146	**0,638**	0,213	-0,091	0,223	-0,158	0,372	0,565	**V**		
-0,069	0,170	0,036	0,131	0,334	-0,533	-0,122	-0,443	**0,696**	-0,432	-0,247	-0,291	**0,609**	-0,020	0,732	-0,214	0,08	**Zn**	
0,318	0,442	0,334	-0,297	-0,223	-0,462	-0,210	0,008	0,003	-0,295	-0,067	-0,180	0,234	0,133	0,216	-0,290	-0,102	0,322	**Z r**



* Total iron oxide

Figure 11 - Correlation diagrams of some selected major and trace elements.

positive correlation (r=0.521) between FeO and P_2O_5 (Figure 11 c). This indicates that these two components were concentrated in parallel with each other in the same environment. In Figure 11, it is seen that V became concentrated in magnetite. Similar ionic radii of V^{5+} (74 pm) and Fe^{3+} (72 pm) played a part in this. The positive exponential correlation between V and FeO indicates that V reached the degree of saturation. On the other hand, it is observed that Ti^{4+} (65 pm) preferred Al^{3+} (63 pm) compounds, for example, muscovite and chlorite (Figure 11 e). The field with high Al_2O_3 - low TiO_2 in the variation diagram corresponds to the sedimentary field (Fernandez and Moor, 1998; Çelebi et al., 2005).

Likewise, the positive correlation between CaO and P_2O_5 results from apatite; and from the linear correlation, it is understood that this also reached the degree of saturation (Figure 11 f). The FeO-V correlation (r=0.785) in magnetite is better than the P_2O_5-F correlation (r=0.417) in apatite (Table 3). Here, the fact that F was bound also to micas and ions of O, Cl, OH and CO_3

partially replaced F influenced the distribution negatively. In addition to these, it is seen from Table 3 that owing to radius similarity and common geochemical behavior, Ba with K (r=0.798), Cr with Al (r=0.644) in micas and Sr with Ca (r=0.662) in apatite, concentrated.

None of the elemental ratios, which are considered important with regard to origin, points out magmatic origin. The ratios of Ca/Sr=127 and Ba/Rb=4.7 correspond approximately to the average continental crust values (117 and 7) (Table 2). Likewise, average Ni/Co=2.9 and Ti/V=6.2 values are lower than the average values of magmatic rocks (2 and 7). In basic rocks, Sr/Ba>1. This ratio is 0.90 in Pınarbaşı, which reflects the ratio in sedimentary rocks.

Niggli values fall within the field of sedimentary rocks of pelitic origin in the alk-al-c/fm variation triangle (Figure 12). This is supported by the distributions in the ACF and mg-c concentration diagrams, as well (Çelebi et al., 2005).

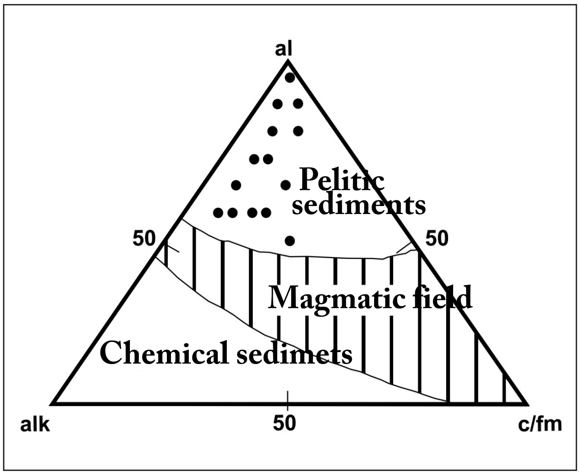


Figure 12- Distribution of wallrock values in Niggli alk-al-c/fm triangle

b) *Values of Fe and P_2O_5 core analyses.*- The samples, the analysis values of which are given in Table 2 are representative samples taken from various parts of the deposit. There-fore, it is not possible to examine the 3. dimension (i.e. its variations with depth) of the deposit by means of these samples. Third dimension examinations are only possible by means of drill core analyses results. However, since only the analyses of valuable raw materials Fe and P_2O_5 are performed on these values (Büyükkıdık and Aras, 1984), it is only possible to examine the relationships of these two components.

There is also a significant positive correlation between analysis values of Fe and P_2O_5 core samples (Table 2) (Table 3 and Figure 13 a). This indicates that Fe and P_2O_5 concentrated in a parallel manner and most probably came from the same source.

As shown above, in all holes, except SP-7, Fe and P_2O_5 concentrations are positive, but they become negative with depth (Figure 5 and 13 b, c). The drill holes in the north are richer with regard to Fe and P_2O_5 tenor and more disseminated compared to the holes in south. No significant correlation (proportional effect) is observed between average grades and standard deviations of the drill holes (Figure 13 d). This feature resulting from the alternation of ore-rich lenses and lean disseminated mineralizations will complicate to maintain an average ore tenor during a possible operation.

Variation of ore reserves with depth is considered to be the indication of an orientation. Orientation is an expression of the dependence of tenors on a distance like sample interval h. This feature requires the use of complex geostatistical methods in the ore reserve estimation for the deposit.

Distribution of rare earth elements (REE)

Magnetite seems to be poor in rare earth elements (REE). Chondrite-normalized REE concentrations are shown in Table 4. According to this table, total REE concentration is lower than 200 ppm. However, magnetites of similar

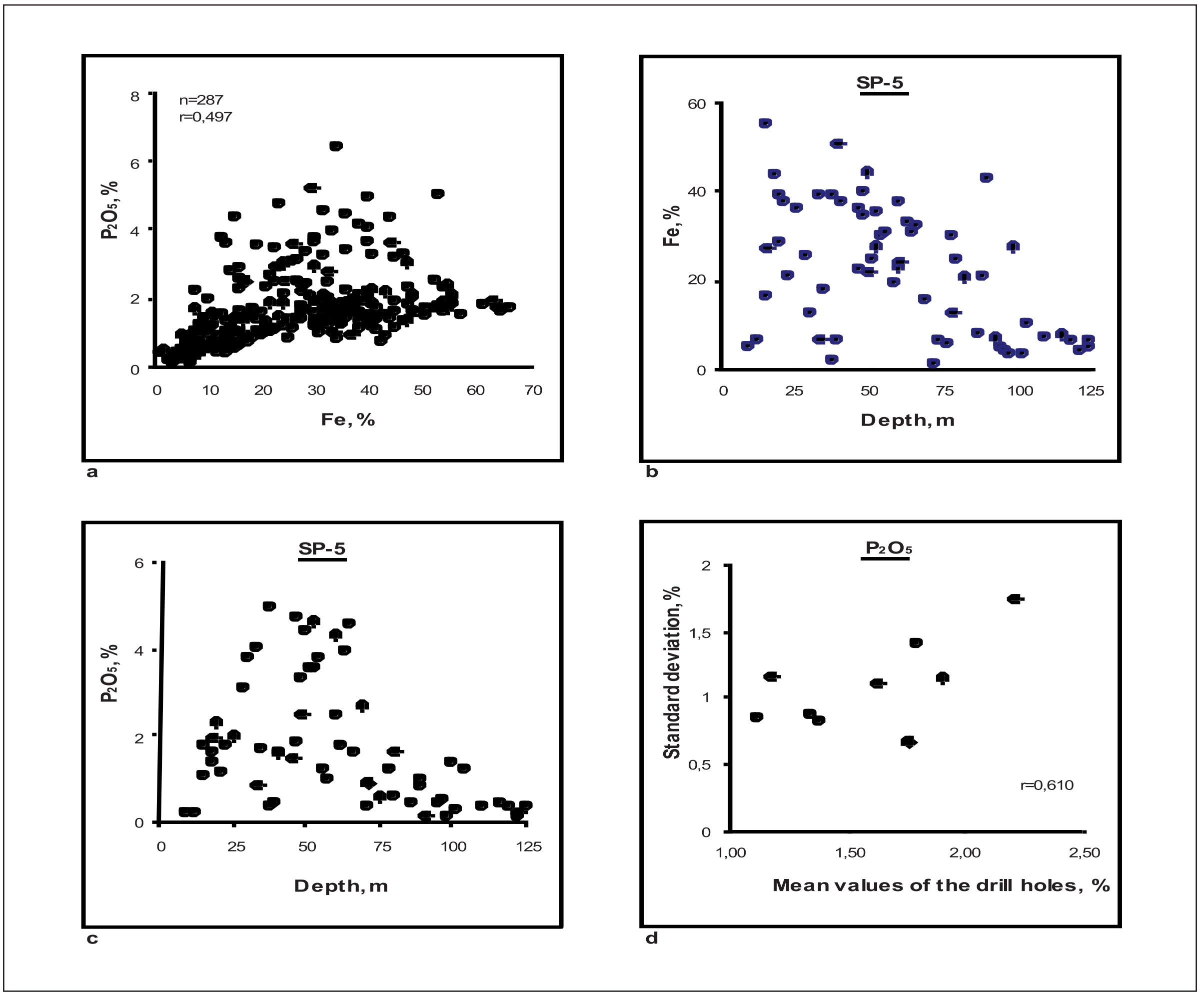


Figure 13- Variation of Fe and P_2O_5 with depth.

deposits, for example, Avnik magnetites contain over 500 ppm and Kiruna magnetites contain over 2000 ppm REE (Frietsch and Perdahl, 1995). This low RRE content denotes that the REEs in Pınarbaşı magnetites did not reach the saturation point. The reason for this may be, for example, low grade of metamorphism, low REE concentrations in the parent rock and in the ore-bearing fluids. In addition, apatite's intake of REE should also be taken into consideration. However, REE distributions in the selected samples are normal. Coefficient of variation varies between 40% (Tm) and 66% (La). This reflects that magnetite possesses a homogeneous composition.

It is observed that light REEs concentrate better than heavy REEs in Pınarbaşı. The first 4 REE, La+Ce+Pr+Nd, constitute 75% of the total REE concentration. On the other hand, mean ratio of La/Yb=3.89 is low. This reflects that the elements were not well differentiated (Ekambaram et al., 1986). This ratio is 1.48 in chondrites and approximately 30 in Avnik.

A low Eu anomaly is observed in the distribution of Pınarbaşı REE, normalized according to

Table 4- Rare earth element values in magnetite

	Sample/Pınarbaşı								
Element	**N-24**	**P-1**	**P-16**	**P18a**	**P-23**	**Ort.**	**Avnik***	**Ünaldı***	**Chondrite****
La [ppm]	23	58	21	22	11	26,92	55,33	126,50	0,245
Ce	70	149	58	69	49	78,68	88,00	217,00	0,638
Pr	7	17	7	7	4	8,41	6,67	19,00	0,096
Nd	30	71	30	27	17	34,80	17,00	53,50	0,474
Sm	9	19	8	7	4	9,46	2,00	7,00	0,154
Eu	2	4	2	1	1	2,07	0,15	0,40	0,058
Gd	9	19	8	6	5	9,43	1,44	5,59	0,204
Tb	2	3	2	1	1	1,75	0,24	0,84	0,037
Dy	10	18	10	5	6	9,70	1,22	4,38	0,254
Ho	2	4	2	1	1	2,08	0,25	0,87	0,057
Er	6	10	7	3	4	5,90	0,64	2,33	0,166
Tm	1	1	1	1	1	0,98	0,11	0,35	0,026
Yb	7	11	8	4	4	6,76	0,81	2,31	0,165
Lu	1	2	1	1	1	1,10	0,14	1,73	0,025
La/Ce	0,33	0,39	0,36	0,32	0,22	0,34	0,63	0,58	0,38
La/Yb	3,29	5,27	2,63	5,50	2,75	3,89	68,30	54,54	1,48

*n=3 ** White, 1997

the chondrites (Figure 14 a). This points out high O_2 mobility. High O_2 mobility oxidizes Eu^{2+} (0.121 nm) to Eu^{3+} (0.109 nm) and causes it to pass into early phases. Consequently, in the environment Eu becomes diluted and cannot be enriched in the crystallization phases, for example, in magnetite. For that reason, Eu gives negative anomaly. Along with this, a slight, positive Ce-anomaly is also observed in the distribution. This shows that Ce is present in the environment as +4-valent and that sea water is not efficient, because sea water causes negative Ce-anomaly (Frietsch and Perdahl, 1995).

In Figure 14 b, REE distribution of Pınarbaşı magnetites is compared with REE distributions of similar deposits in Turkey. There, it is seen that, in Pınarbaşı magnetites REE differentiation is slightly negative, Eu anomaly is weak and heavy REEs are more concentrated. This demonstrates that Pınarbaşı apatite-bearing magnetite mineralizations developed differently from mineralizations of the Bitlis Massif deposits.

The average REE concentration of 900 ppm of Pınarbaşı apatites is 4.5 times more than that of magnetites. Differences are observed in REE distributions of the phases of magnetite and apatite, xenotime, monazite and allanite, which are known as REE- carrier minerals (Çelebi et al., 2005; Kalkan, Ağcıl and Çelebi, 2004). While light REEs concentrate in magnetite, monazite and allanite, in apatite and xenotime concentrate heavy REEs. Here, crystal structures and ionic radii of the minerals played an important role. For example, heavy REEs having smaller radii concentrated in apatite and xenotime with smaller ionic lattices (Ca^{2+} [0.108 nm] and Y^{3+} [0.098 nm]), and light REEs concentrated in monazite and allanite having larger crystal structures ($REEO_9$ polyeder) (La^{3+} [0.113 nm], Ce^{3+} [0.109 nm] and Th^{4+} [0.108 nm]).

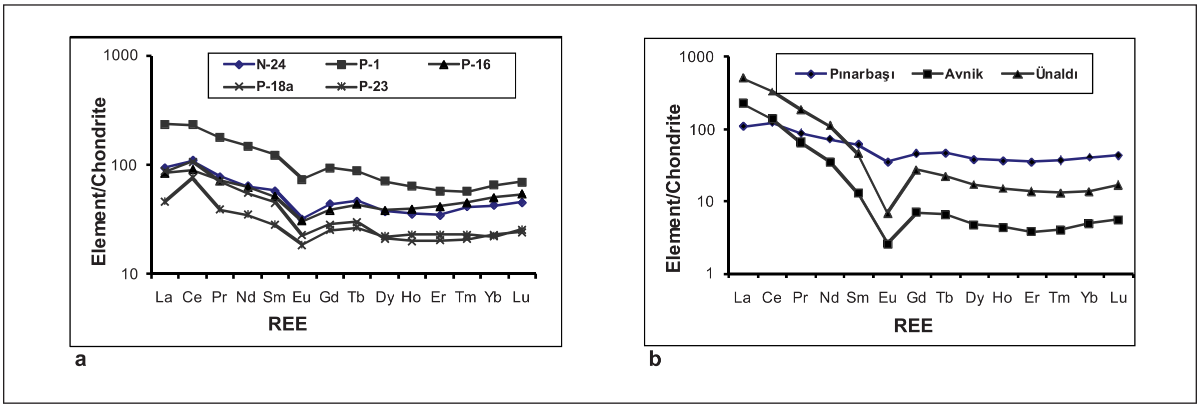


Figure 14 - Distribution of chondrite-normalized rare earth elements of magnetites, a: in Pınarbaşı magnetites, b: in apatite-bearing magnetite deposits of Turkey (table 3)

Frequency distribution

Fe and P_2O_5 analyses were performed on all of the approximately 300 core samples taken from 9 holes drilled by MTA until 1983 in the Pınarbaşı deposit (Büyükkıdık and Aras, 1984). In the present paper, 287 of these were chosen for evaluation.

Distribution calculations performed according to Sturges rule give both Fe and P_2O_5 weak ore type and 2 main populations (Figure 15 a, b). This feature is maintained both in cumulative frequency distribution (Figure 15 c) and in logarithmic frequency distribution (Figure 15 d). This indicates the presence of two different ore types. For example, lean (disseminated) and rich (banded) ore types. These mineralizations may also be the product of 2 different functions.

When looked at logarithmic Fe distribution, it is seen that it approaches normal when distribution symmetry changes (Figure 15 c), whereas P_2O_5 distribution becomes normal (Figure 15 d). This shows that P_2O_5 is distributed more regularly compared to Fe. Log normal distribution is considered a development peculiar to magmatic functions (Ahrens, 1954 *a* and *b*). Consequently, this result can be interpreted as the reflection of a magmatic activity.

Fe distribution is flatter than the theoretical normal distribution, whereas P_2O_5 distribution is peaked. This result expresses that Fe is accumulated in several minerals, whereas P_2O_5 is accumulated only in apatite. Microscopic findings also confirm this.

STRUCTURAL ANALYSIS

In order to determine some important structural features of the ore distribution in the Pınarbaşı apatite-bearing magnetite deposit, such as the best sample interval, margin of error and alternation, for the values of Fe and P_2O_5 core analyses, according to the equation,

$$\gamma_{(h)} = \frac{1}{2n}\sum_{i}^{n}(x_i - x_{i+h})^2$$

in drill holes, vertical variograms and in the deposit horizontal variograms (in N-S direction) were computed. In this formula, n= number of samples, x_i= analysis value, x_{i+h} = value of the sample at a distance h to xi sample, h= sample interval (m, Figure 16).

The computed variograms show similarity in Fe and P_2O_5 distributions, high nugget effect (~25%), optimum range (around 10 m), trend and alternation.

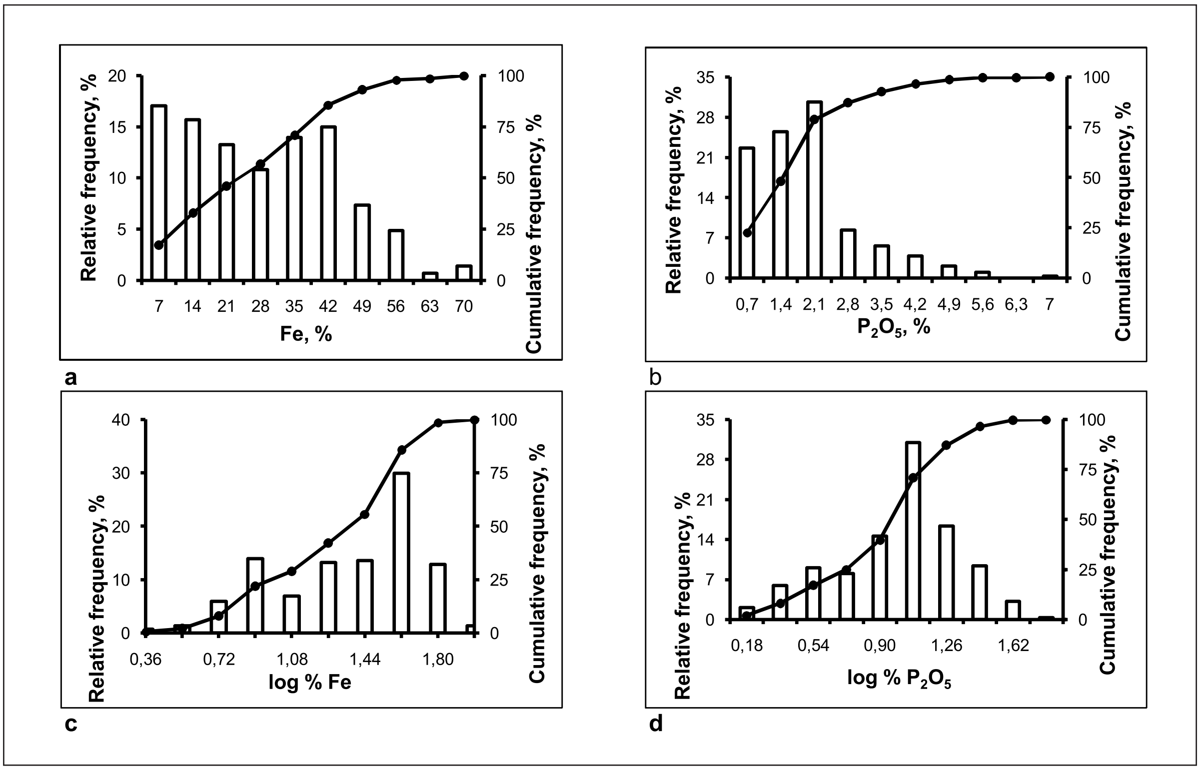


Figure 15- Fe and P_2O_5 frequency distributions of core samples (n=287)

Nugget effect is the beginning point of the average variogram curve on the ordinate (approximately and in %). Optimum range is the point where values become independent; and trend is the variation of the ore with depth. This is understood from the fact that variogram values approach zero with the increasing depth. Alternation shows itself with increasing and decreasing variogram values and it means the alternation of ore horizons with zones devoid of ore (i.e. wall rock) (Figure 16 a and b). These characteristics in an ore deposit are attributed to log normal distribution by Wellmer (1989), Akın and Siemens (1988) and David (1977).

The alternation towards depth is also observed in the variograms of average drill-hole values taken in north-south direction (Figure 16 c and d). Here, optimum borehole interval is around 150 m. Margin of error in this direction is estimated about 10%. It is not possible to observe the variation in east-west direction due to lack of sufficient number of boreholes.

ECONOMIC POTENTIAL OF THE DEPOSIT

Geological, geochemical and drilling data constitute the basis for the evaluation of the deposit.

Reserves and tenor distribution

MTA explored Pınarbaşı apatite-bearing magnetite deposit by means of 9 drill holes amounting to 1517 m in total. Nine holes are not considered sufficient for this deposit. Structural analyses show that optimum sample interval is 10 m, and optimum drill hole interval is 150 m (Figure 16). Consequently, the present drill hole interval reaching 300 m is too large. New reserves may

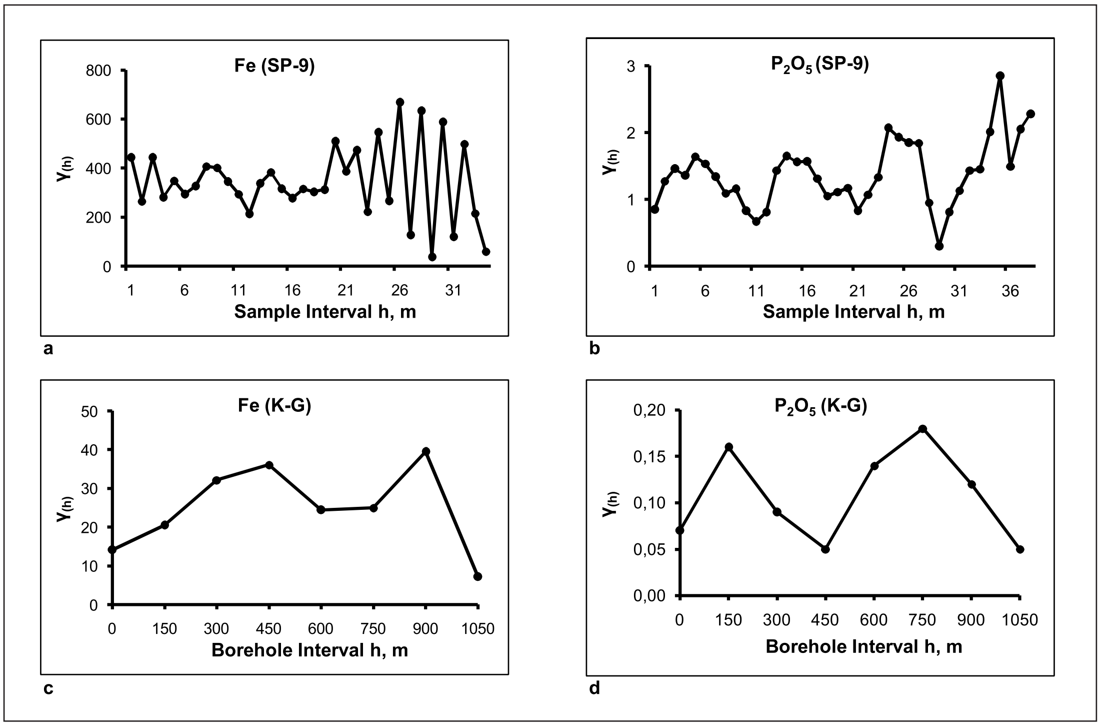


Figure 16- Fe and P_2O_5 variograms computed in some selected holes (a, b) and in N-S direction give the optimum sample interval as approximately 10 m, and optimum drill hole interval around 150 m.

be gained with additional drill holes and developing the drilling network westwards. In addition, the computed reserve quantities are not classified as proved reserves due to low core recovery (v= core length x 100 / drilling advancement). At least 80% core recovery is required for proved reserves (Wellmer, 1989); however, average core recovery is 45.61% at Pınarbaşı.

Pınarbaşı apatite-bearing magnetite deposit was studied by a lot of researchers with regard to economic potential (Sınacı et al., 2003, Güneş, 1994; Büyükkıdık and Aras, 1984). Within the scope of this research, taking the principles in Figure 5 as a basis and using parallel section method, a magnetite reserve of 78 Mt having 35.07% Fe and 1.57% P_2O_5 (for ores having over 20% Fe) was calculated by Sınacı et al. These results, checked with triangular-prism method, are in accordance with the findings of the previous researchers. Güneş (1994) gives 66.2 Mt (total) magnetite reserve having 36.04 % Fe and 2.07% P_2O_5; Büyükkıdık and Aras (1984) give 69.2 Mt (total) magnetite reserve having 28.56 Fe and 2.01% P_2O_5. Accordingly, in Pınarbaşı deposit, there exist metals (Fe, V) and valuable mineral raw materials (F, P_2O_5, REE) approximate quantities of which are given in table 5.

These data show that the quantity of the reserves of the deposit is sufficient for exploitation, but the tenors are low. Çelebi (1989), Pfeufer (1997) and Ranjbar (2002) experimentally demonstrated that various apatite-bearing magnetite ores could be enriched by floatation and along with magnetite concentrate, apatite concentrate could also be obtained. Akar (1983) proved that Pınarbaşı ores could also be enriched and that P concentration in magnetite could be lowered below 0.05%. According to

Table 5- Valuable raw material content of the deposit according to various researchers.

	Fe [Mt]	**P_2O_5** [Mt]	**V*** [kt]	**F**** [kt]	**NTE**** [kt]
1.	27.30	1,22	30	114	3
2.	23,90	1,37	27	100	3
3.	19,80	1,39	22	120	3,10

1 Sınacı et al., 2003 **2** Güneş, 1994 **3** Büyükkıdık and Aras, 1984 *in magnetite, **in apatitte

Pınarbaşı magnetites are pelletizable. Accordingly, magnetite and phosphate concentrates with properties adequate to be marketed under present conditions can be obtained.

In this study, the possibilities of gaining present Fe and P_2O_5 raw material values of the deposit are examined. These are vanadium (V) content of magnetite; and fluorine (F) and rare earth elements (REEs) contents of apatite. The results of the examination revealed that 3.46 % F concentration of apatite is normal, but 0.08% V concentration of magnetite and 0.09 REE concentration of apatite are low. In addition, yttrium shows a significant concentration with 0.10%. Concentrate production of some minerals, such as monazite (La-Ce-Th[PO_4]), xenotime (Y[PO_4]) allanite/orthite (Ce-epidote), can be experimented. In addition to these, radon gas (Rn), released during the disintegration of uranium (100 ppm) which is contained in apatite, may be utilized in earthquake early warning researches and in the exploration for new deposits.

Possible mining parameters

In case of a possible mining, the deposit can be strip-mined thanks to considerably low ratio of overburden/ore <1/1. However, in order to get the ore in depth, underground mining will be necessary. The variation of the ore with depth and the state of the overburden is given in Figure 5, section AA' and Figure 6. The extracted ore should be enriched. In this way, phosphate percentage of the magnetite concentrate will be lowered and its quality will be upgraded as well as the lean ore will be utilized.

Along with the proved and probable reserves, there are inferred reserves with low tenor (< 20% Fe) around the deposit and at greater depths (Figure 6). The major problem for magnetite ores, which can be readily enriched by means of magnetic separators, is the phosphorous, not wanted in blast furnace. P should be <0.05%. But, P can also be separated as explained above. However, the fact that the apatite is fine-grained will increase the cost. Although P is harmful for steel production, it is the raw material for phosphoric acid and superphosphate. Turkey procures all of its phosphate demand by import (Çelebi, 2007). That's why P is a highly important raw material. Hence it would be useful to take it into consideration.

Vanadium does not possess a concentration to be a value-adding component for steel production. On the other hand, recovery possibilities for energy storage (battery) can be researched (Çelebi, 2001). Furthermore, fluorine content of apatite seems to be adequate for F production. It can be processed in a hydrofluoric acid plant to be set up and some of the expenditures can be covered by the profit to be obtained from it.

Pınarbaşı apatite-bearing magnetite deposit can be defined as a medium-scaled iron deposit. This deposit is a great potential and an important resource for a country like Turkey which procures its requirement of iron ore, phosphate and fluorine by import. The deposit with an approximately 3.7 Mt / a optimum capacity will have an optimum life of approximately 18 years (Çelebi et al., 2005).

Significant investment for infrastructure is needed prior to operation. Reinforcement of existing transportation roads, construction of new ones, especially construction of a railroad, supplying water and energy are investments having top priority. For water, the nearest source Çat Dam and for electrical energy, Karakaya Dam can be considered. The ore can be processed under optimum conditions at İsdemir (İskenderun). And a telpher may be set up to transport ore to a loading station to be established in Sürgü or Doğanşehir.

Such a project, first of all, by making use of Turkey's own resources, will save foreign exchange on a large scale for the iron ore importing country. Related industry investments, such as phosphorous and fluorine processing plants which will come to the district because of mining will contribute to the development of the area. Lastly, an iron and steel plant, which will be set up in Malatya and will process iron ores of Hasançelebi iron deposit,as well, may be taken into consideration.

CONCLUSION AND SUGGESTIONS

The valuable mineral raw materials of Pınarbaşı apatite-bearing magnetite are slightly matitized magnetite and fluorapatite, bound in chlorite-sericite schists. The most important gangue minerals are fluorapatite and quartz. Results of analyses give average contents of Fe and P_2O_5 as ~ 35% Fe and 3% P_2O_5. Magnetite ores contain high level of Al and numerous trace elements, such as V, Zn and N.

According to the results of geological, mineralogical and geochemical examinations, Pınarbaşı apatite-bearing magnetite deposit is a medium-scaled, classical Kiruna-type apatite-bearing magnetite deposit. Formation of this type of deposits is a controversial subject. Despite numerous geological, mineralogical and geochemical studies continuing for more than 100 years, the formation of 'apatite-bearing magnetite deposits' or 'Kiruna-type deposits' could not be explained nor could a generally accepted 'formation model' be developed. Current discussions are concentrated on 'magmatic intrusion' and 'sedimentary' models.

Metamorphism complicated the synthesis of the original development by obliterating the traces of the old geological developments. However, field and microscopic observations such as chlorite-sericite wall rock, horizontal position of the ore deposit, bedded structure and especially, apatite's fine-grained structure; and such geochemical findings as high Al concentration of the wall rock and low trace element content of magnetite associates a sedimentary origin. Hydrogen isotope analyses reflect sedimentary rock values and support geochemical findings. These findings indicate that parent rocks of present-day metamorphic rocks of chlorite-sericite schists are sediments of pelitic origin or tuffs.

Fe and P required for the primary enrichment of recent magnetite and apatite were most probably carried as ions and deposited simultaneously with the wall rock. The harmonious distributions of Fe and P in the deposit support this thesis. Both of these components decrease with depth. Banded structure or wall rock-ore alternation reflects a rhythmic change and strengthens the possibility that deposition took place in a calm environment. The iron ore which formed first was most probably hematite and the primary minerals of apatite were phosphates.

Lastly, in Cretaceous the temperature which increased with ophiolite development, the reducing effect of pH and Eh values, at least 0.4 GPa pressure and conditions of metamorphism at 370 °C transformed hematite into magnetite and phosphates into apatite. As orientational forces of metamorphism arranged the wall rock with schistosity and foliation, the ore accommodated itself to the orientation as massive, banded and disseminated. With subsequent E-W compression movements, erosion and transportation, the deposit took its present shape.

Mineralogical examinations show that deposit units are primarily composed of oxides and silicates. The ores with geochemically pure composition consist of magnetite, hematite (martite and specularite) and goethite. The content of fluorapatite, the most important gangue mineral of magnetite, reaches in places up to 30%. It is followed by quartz, chlorite, sericite and micas. Rutile, zircon, monazite and xenotime are rarely observed.

Geochemical analyses show that Al, Mg and Ca follow Fe and P. Alkali content is around 1.5%. In the deposit P was enriched the most with 17- fold compared to Clarke values. Fe 9-fold, F 8-fold and V was 4-fold enriched. On the other hand, Na 7-fold K and Mg were 3-fold impoverished. The most important trace element of magnetite, which is considerably pure, is V with average 800 ppm. Apatite is also present as a minor element with 3.46% concentration of F. Furthermore, rare earth elements with an average concentration of 900 ppm in apatite may be considered significant.

Elements present a logarithmic distribution. Correlation analysis shows the existence of a significant positive correlation between numerous pairs of elements. The optimum negative correlation exists between Fe and SiO_2. However, there is a significant positive correlation between Fe and P. This shows that Fe and P developed parallel to each other. Fe-V correlation is better than F-P, which indicates that F concentrated in micas as well as in apatite.

Radiometric (Ar-Ar) age determination gave 66 and 48 Ma. Of these, the older 66 Ma is explained with the metamorphism realized with ophiolite development (Campanian). And 48 Ma is accepted as the age of a secondary metamorphism, retrograde metamorphism or tectonic mobilization (Eocene).

Structural analyses give the spherical variogram type which reflects a hole effect. These show that optimum sample interval is 10 m, optimum drill hole interval is 150 m and there exists a proportional effect and orientation.

Pınarbaşı deposit can be defined as a classic Kiruna-type deposit of sedimentary origin. Similar deposits are Kiruna, Cerro des Mercado, El Laco and Bafq deposits. Similar deposits in Turkey are Avnik and Ünaldı deposits. The deposit is not considered to be economically mined under present conditions due to its low content of F and high content of P. However, by-products such as P, F, V and rare earth minerals which can be recovered along with Fe increase the value of the deposit and earn it the feature of an important mineral raw material source of the future.

ACKNOWLEDGMENTS

This study was realized within the scope of the project YDABÇAG-101Y119 of Tübitak. For that reason, we are grateful to Prof. N. Yetiş, President of Tübitak. We would like to extend our sincere thanks to Prof. Dr. Mehmet Önal (İnönü U.) for his great help during field works, Engineer, Msc. E. Kılınç (Kromsan, JSC/ Mersin) for his interest during sample preparation and Asst. Prof. G. Matheis (Berlin Technical U.) for his support during laboratory works.

Manuscript received April 22, 2008

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