報　文

553.6 (560)

Sulfur Ore Deposits in Turkey

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Abstract

Keciborlu mine is the only sulfur mine under working in Turkey, producing about 3,000t of refined sulfur per month, that is, three-fifths of the monthly demand of the country. It is an impregnation and replacement type of deposit formed in a pyroclastic formation beneath a thrust sheet of Cretaceous limestone and associated serpentinite dikes of irregular forms. Other types of sulfur ore deposits are also seen; six sublimate deposits in the Quaternary volcanic regions, four impregnation deposits in the Tertiary volcanic regions and a volcanic sedimentary deposit formed in a caldera-like basin. None of them, however, have been extensively prospected yet (Fig. 1).

Fig. 1　Distribution of sulfur ore deposits in Turkey.

Introduction

The authors worked for the Mineral Research and Exploration Institute of Turkey (MTA in Turkish abbreviation) for two years (1971–1973) as geologists sent by the Overseas Technical Co-operation Agency of the Japanese Government. They made a brief geological investigation of sulfur ore deposits in Turkey in 1972. The outline of their reports on the ore deposits is pre-

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sented here. Their allotted portions in writing the present report are as follows.

OTA ..... general geology

MADO ..... ore deposits

In the course of their field investigation, they were assisted by the following geologists of the Institute.

East Anatolia ..... Gungor MEHMET, Mehmet OKUT and Akay FADIL

West Anatolia ..... Baki AKCA

Turkish proper nouns cannot always be put into English properly, because some Turkish letters are deficient in Roman alphabet. It is customarily done, however, that the nouns in question are put into English, paying more attention to their spelling rather than their pronunciation for the readers' convenience. The name of the only sulfur mine under working, for instance, is spelt Keciborlu but not Kechiborlu, though the latter may better represent its correct pronunciation.

Impregnation and Replacement Deposit

Keciborlu mine, the only sulfur mine under working in Turkey, is the single example of this type. The sulfur is mainly used for fertilizers and agricultural chemicals. The production of refined sulfur is about 3,000t a month, which is equivalent to three-fifths of the monthly consuming amount of sulfur in Turkey. The ore is mostly obtained by underground mining, while open-cut mining is now under developing. The production of crude ore from the former is 225t a day, in which the ore of S 75% is 75t and that of S 45% is 150t. The ore is carried to the wet refinery by trucks, where it goes through such processes as crushing, floatation, smelting in autoclave, etc. The final product is sent off from the nearby railroad station.

1. General geology (Fig. 2)

The oldest rocks in the area are limestone and serpentinite, the both being of probably Cretaceous age. The limestone occurs as if it overlay the serpentinite in the field, but the latter penetrates into the former in irregular forms as actually seen along the open-cut walls. There is a sedimentary formation of volcanic origin called Keciborlu Formation, which unconformably overlies the above-mentioned rocks. The formation is composed of tuff, tuff breccia and conglomerate, in which gravels of limestone and serpentinite are contained. So-called flysh is distributed

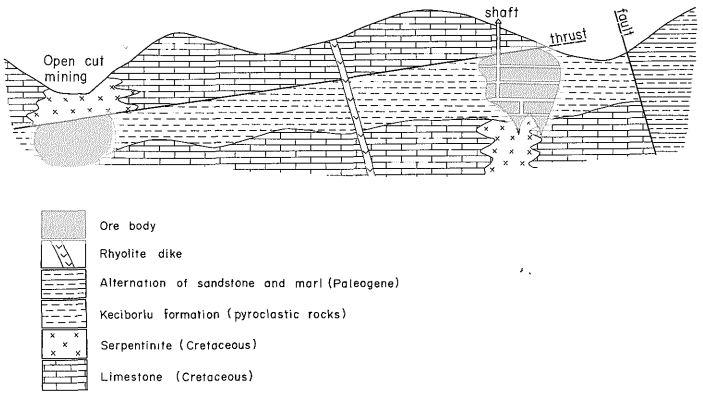

Fig. 2 Idealized geological section of Keciborlu mine.

to the east of the ore deposits. It is an alternation of sandstone and marl, fine sandstone being predominant. The geological age based on fossils is the Paleocene to Lutetian, or middle Eocene, according to an unpublished report stored in the MTA. Even though penetrated by numerous veinlets of calcite, it has not undergone any remarkable mineralization alteration. It seems to be in fault contact with the Keciborlu Formation. After the sedimentation of the Keciborlu Formation, the limestone including serpentinite were thrust up. Afterwards, rhyolite dikes of probably Tertiary age intruded into all the mentioned rocks in the NW-SE direction. The ore-forming fluid came up to form the sulfur ore bodies preferably in such favorable rocks as sedimentary rocks of volcanic origin, or the Keciborlu Formation. The overlying limestone and serpentinite were also partly impregnated with sulfur. The rhyolite dikes do not seem to have genetical relations with the ore deposits, because the deposits are presumed to be related to the Quaternary volcanic activity.

2. Ore deposits

There are two major ore deposits, 2.6 km apart with each other, one of which is under working by means of underground mining, the other being by open-cut method.

2.1 Open-cut ore deposit (Fig. 3)

The deposit is presently mined at two sites, but it seems to be of a single ore body. The sulfur is partly impregnated in the overlying sheet of limestone and serpentinite, preferably in the latter as is seen along the open-cut walls. The serpentinite penetrates into the limestone irregularly and complicatedly. Remains of solfatara which seem to have been active until quite recently can be seen at places in the open-cut walls. The average grade of the ore of sublimate sulfur obtained on and around the solfataras is S 15% or so, while the ores from deeper horizons obtained by drilling generally show higher grades often reaching S 70%±. It seems that the Keciborlu Formation, lithological character of which is favorable for impregnation of sulfur,

Fig. 3 General view of the open-cut of Keciborlu mine.

The white rock is limestone, the dark one being serpentinite. The ore body beneath the mentioned rocks is undeveloped, though its existence has been ascertained by drilling.

exists beneath the thrust sheet of limestone and serpentinite. The thrust sheet may have played the part of cap rock during the mineralization.

2.2 Underground mining ore deposit (Fig. 4 and Fig. 5)

The surface rock around the mine shaft is composed of limestone, and is underlain by sedimentary rocks of volcanic origin regarded as the Keciborlu Formation, in which a massive sulfur ore body of irregular shape has been found. The ore deposit is of impregnation and replacement type of S 40–70%. The limestone and serpentinite, safely considered to be the basement rocks, partly appear at the lowest level. The shape of the ore body is remarkably uneven at the base, depending on the rugged surface of the basement rocks. There also exist root-like branches extended into the basement. They might have been the passages of the ascending ore-forming fluid. The limestone cropping out around the shaft mouth seems to have acted as the cap rock during the mineralization.

In general, the ore with weak opalization is not so hard. It is composed mainly of sublimate sulfur, the evidence for replacement being not conspicuous. As compared with the ores of Japanese typical impregnation and replacement sulfur ore deposits (MUKAIYAMA, 1970), the ore of this mine shows less features of replacement processes. Accordingly it may be called an intermediate type between the typical impregnation and replacement deposit and the typical sublimate deposit.

Fig. 4 General view around a shaft of Keciborlu mine.
The sulfur ore is mostly carried out of this shaft, which is 80 m deep.

Sublimate Deposits

Following six ore deposits belong to this type. All of them are related to the Quaternary volcanic activity.

1. Saraykoy

The area is nearly 30 km northwest of Denizli. The low hills, in which sulfur ore deposits are dotted, are composed of a well-stratified alternation of tuff, lapilli tuff and tuff breccia. The

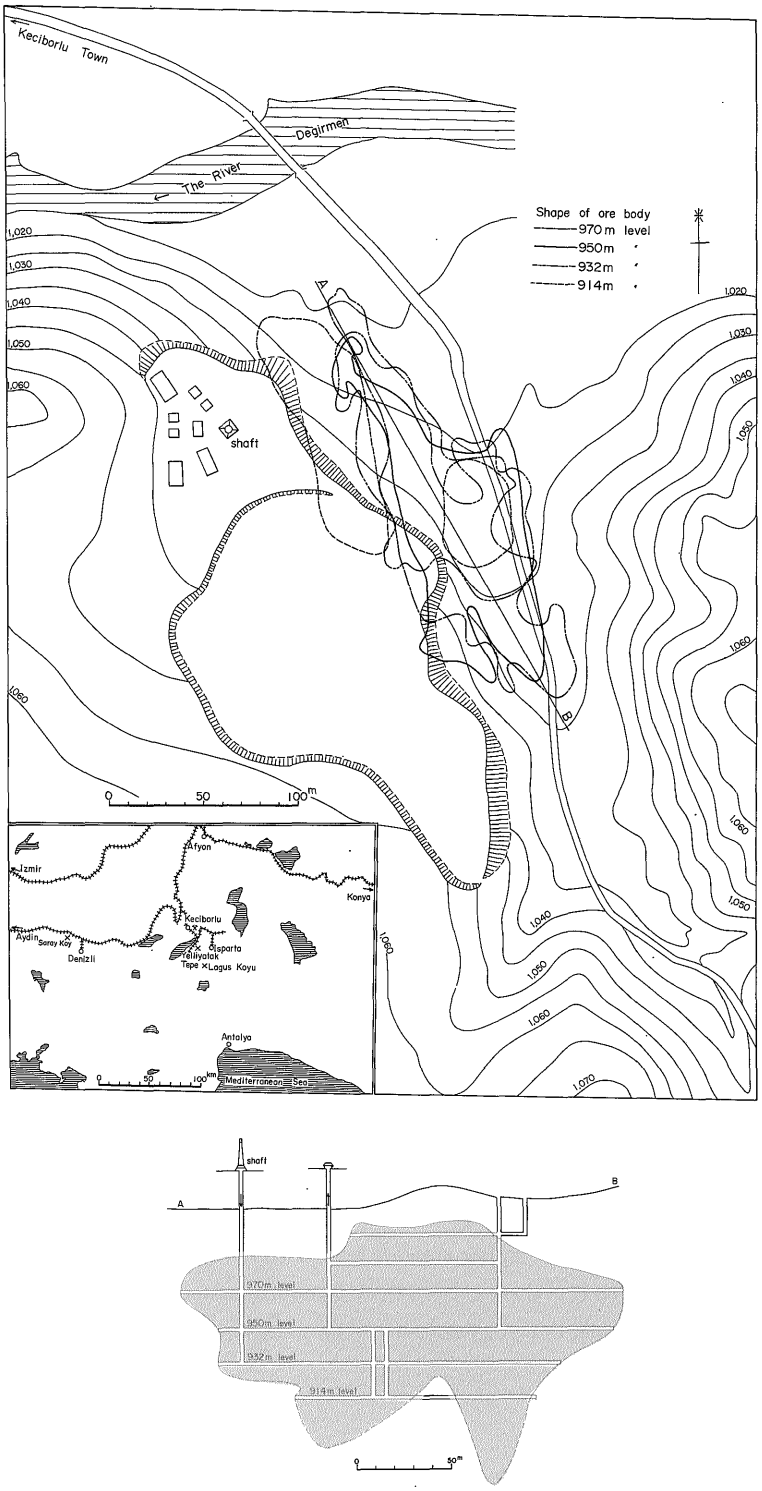

Fig. 5 Ore body of underground mining of Keciborlu mine.

ore is of sublimate sulfur on solfatara walls, deposited from sulfuric gas that ascended along small fissures in the country rocks. The ore deposits were once worked at places in 1936–37 and a total of 200–300t of ore (S 50%) was mined, but eventually all the deposits were closed down because of their unprofitable exploitation results. The neighbourhood is an extensive geothermal area, in which drilling, 300–1,000m in depth, was carried out at several places. Not only gushing steam out of some of them, but also there are natural fumaroles steaming in boiling ponds. As mentioned above, the area is composed mainly of a thick layer of pyroclastic rocks with no intercalation of lavas. This may suggest that the area is rather unfavorable for formation of large sulfur ore deposits of impregnation and replacement type. Even if drilling or prospecting drifts should be made, they would be confronted with many difficulties due to steaming somewhere at shallow depth.

2. Yelliyatak Tepe

The area, 20 km SSE of the Keciborlu mine, is situated near the top of a mountain, several hundred meters in relative height, and is composed of a thick layer of sandstone of flysh type. The layer is partly covered by andesite tuff breccia, 1–4m in thickness. In the area, there are some spots in which small quantities of sublimate sulfur are found together with gypsum and iron sulfide in decolored sandstone and tuff breccia due to silicification and argillization. Though situated on a presumed tectonic zone which connects Golcuk Lake and the Keciborlu mine, the area is composed of a thick layer of sandstone, not intercalated with any favorable rock for formation of sulfur ore deposits. Trenching was done at some spots, but proved the area to be of no economical importance. Though the mountain has been considerably dissected, there still remain some pieces of inverted conical topography just like explosion craters. Many solfataras must have existed there, because the rocks underwent sulfuric alteration. The spots in question, however, cannot be promising, for they lack various kinds of favorable conditions for formation of sulfur ore deposits, e.g., interposition of lava flows.

3. Lagus Koyu

The area, 40 km SSE of the Keciborlu mine, is situated at the northern outside of the mountain range surrounding Golcuk Lake, which is likely a caldera. The area is composed of a thick layer of pyroclastic rocks, mostly andesite tuff, which appears to be intercalated between lower and upper andesite lava flows. In the pyroclastic rocks, about 100m thick, there are extinct and active solfataras at places with remarkably clayey alteration zones accompanied by small quatities of sublimate sulfur. The upper andesite lava is also partly altered. Drilling near active solfataras, however, proved that there exists a thick layer of sandstone of flysh type, the basement rock as it is, beneath the mentioned pyroclastic rocks, indicating that the lower andesite lava is lacking at this site.

4. Nevsehir

It has been reported that there is a sulfur ore deposit on the northern flank of a Quaternary volcano, south of Nevsehir. This seems to be a sublimate deposit of small scale formed on and around solfatara walls, judging from the oral communication with geologists of the MTA.

5. Diyadin

5.1 General Geology (Fig. 6)

The area is situated at the western foot of Mt. Tendurek, one of the Quaternary volcanoes, which rises high in eastern Anatolia. The oldest lithologic unit of the area is the Permian metamorphic rocks consisting mostly of sericite schist and quartzite. The rocks are exposed at places nearly in the NW-SE direction, implying the existence of a tectonic line. The rocks are intruded by a granite stock and associated quartz porphyry dikes.

The Cretaceous formations distributed to the east and the north of Diyadin are composed mainly of limestone and ophiolitic rocks, and are overlain by a well-stratified Neogene formation composed mainly of sandstone, tuff and tuff breccia. Travertine, widely distributed on the Neogene formation, seems to have accumulated separately in several basins.

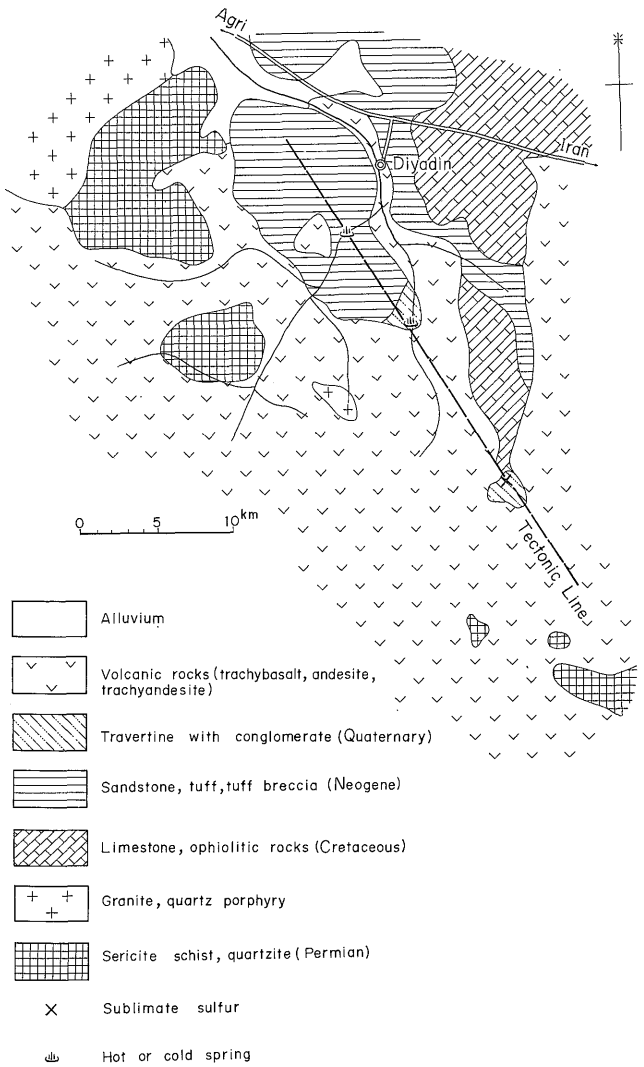

Fig. 6 Idealized geological map of Diyadin district.

Volcanic rocks, mostly lavas of probably Quaternary age, are extensively distributed on the travertine and older formations. They can be classified into trachybasalt, andesite and trachyandesite. The original topography of the trachyandesite lava flow from a crater at the top of Mt. Tendurek is well preserved, suggesting that it is of Recent age. At the last stage of the volcanic activity, steam explosion happened to form pyroclastic cones at the point marked with a cross in Fig. 6 and successively sulfur-containing gas came up. Formation of calcium carbonate cones is still continuing at one of the hot springs (the southern one on the map). As shown on the 1:500,000 geological map "Van", published by the MTA, there are some small faults in the Neogene formation around Diyadin, their directions being nearly NW-SE. The two hot springs and the pyroclastic cones are arranged on a line with the same direction, and the exposures of the Paleozoic formation and the granite also follow approximately this direction.

5.2 Ore Deposits

The most remarkable place of producing sulfur in this area is about 20 km south of Diyadin, or the above-mentioned point marked with a cross on the map, its height being about 2,650m above sea level. It takes about 1.5 hours by jeep from Diyadin. There is no road after halfway from Diyadin. In a basin surrounded by the travertine and overlying volcanic rocks, there are five pyroclastic cones, 10m or so in height. Sulfur impregnation with altered zones is seen mainly in and around the pyroclastic cones and partly at the edge of a trachyandesite lava flow probably of Recent age. There also exist solfataras and cold springs. A limonite bed with the average thickness of 30 cm occupies an area of 50m by 100m. To the southwest of the pyroclastic cones there is a talus deposit mostly composed of boulders of the trachybasalt lava. Small outcrops of tuff or tuff breccia of presumably Neogene age are observable at places under the talus deposit. Sulfur impregnation is found even in the tuff or tuff breccia and the talus deposit. The mentioned cones are all accumulations of fragmental but rarely rounded boulders, fist-sized or smaller and mostly of sericite schist and quartzite accompanied by small quantities of limestone and others. It is safely considered that the rock fragments mainly from the Permian formations were blown up into the air by steam explosions to form these cones. The rounded boulders are thought to have been derived from conglomerate intercalated in the travertine.

The surface of the pyroclastic cones and their surroundings are often yellow due to the sulfur impregnation. The sulfur-bearing parts extend over an area of 100m by 100m as a whole. The sulfur, however, forms a fine mixture with clay, coating the rock fragments mainly beneath the surface of the cones. Relatively high concentration of sulfur is generally seen in the range of 20–25 cm, 1m at most, beneath the surface. The ore deposits might be of little economical importance, judging from their quality and scale as well as the accessibility.

6. Baskale

6.1 General Geology (Fig. 7)

The area is in the northeastern corner of Turkey and is reached by jeep in about three hours from Van, a town on Lake Van. The river Zapsuyu flows down southward for Hakkari through the central part of this area. The height of Baskale town is 2,315m above sea level. Mountains of comparatively gentle slope successively rise around the town. The oldest rock in the area is limestone of probably Triassic age. Next comes the upper Cretaceous formation composed of

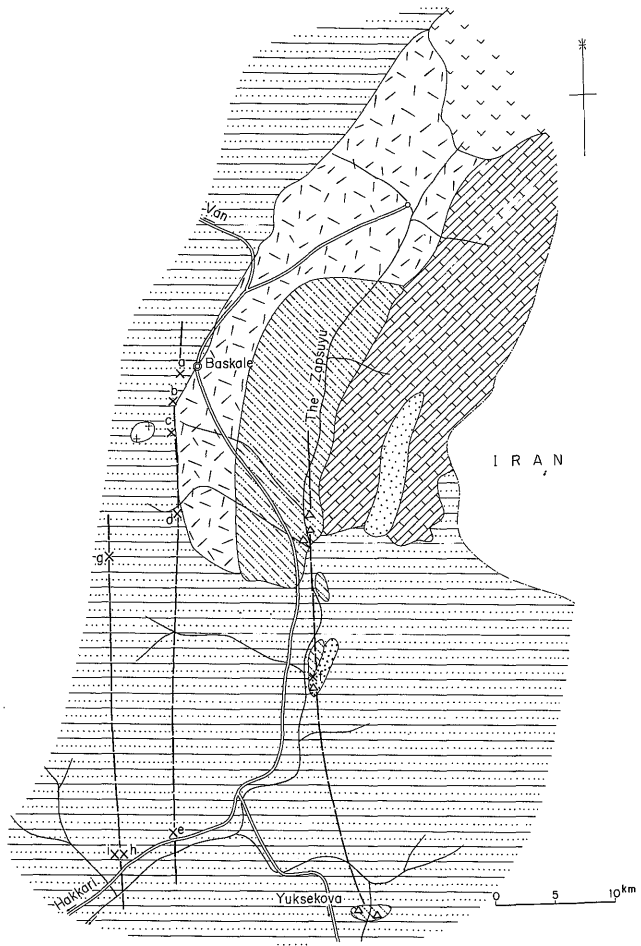

Fig. 7 Idealized geological map of Baskale district.

phyllitic clayslate, phyllitic sandstone, limestone and ophiolitic rocks with a folding axis in the E-W direction due to the Alpine orogenic movement. The formation is intruded by a diorite stock. The Eocene formation of flysh type is distributed to the east of the Zapsuyu. The Neogene formation overlying the mentioned rocks is composed mostly of tuff, lapilli tuff and tuff breccia, and is extensively distributed in this area forming gently sloped hills. Travertine is common along the Zapsuyu, covering the Neogene formation. Terrace deposits of Pleistocene age overlying the

travertine form flat plains. Volcanic rocks of Quaternary age occur about 40 km to the northeast of Baskale. They form an isolated volcanic area with trachybasalt and andesite lavas, andesite welded tuff and rhyolite pumice flow. The trachybasalt is seen as lava plateaus in northern part of this volcanic area, while the andesite lavas are common in the rest of the area. In the southernmost part, the andesite welded tuff overlies a thick accumulation of the rhyolite pumice flow, which represents a striking view peculiar to dissected pumiceous deposits. The sulfur mineralization which is to be stated later, seems to be related to the mentioned andesite activity, that is, of Mt. Haravil, one of the Quaternary volcanoes.

6.2 Ore Deposits

Impregnation of sublimate sulfur, hot or cold springs and their precipitates, and solfataras can be seen at places. There appears to be a trend that their situations are arranged in three parallel zones as shown in Fig. 7, all being nearly parallel to the course of the Zapsuyu.

(1) The middle zone is situated partly along the boundary or tectonic line between the Cretaceous and the Neogene formations (spots a, b, c, d and e in Fig. 7). In the zone, there are five spots impregnated with sublimate sulfur often accompanied by small quantities of iron sulfide. They are found mainly in phyllitic rocks of upper Cretaceous age and partly in tuff breccia of Neogene age. The grade of sulfur ore is estimated to be S 10% or so, all being of small scale. The largest one occupies an area of nearly 50m by 30m. The sulfur occurs only superficially, 1m thick at most. There are cold springs or solfataras in some spots.

(2) The eastern zone partly follows a presumed tectonic line between the Neogene and the Mesozoic formations, the latter being composed of limestone and partly overlain by the Eocene formation of flysh type (spot f and calcium carbonate cones). The zone is situated nearly parallel to the Zapsuyu. There are many calcium carbonate cones, which are being formed from springs gushing out of their tops. The spot marked "f" on the map is the most remarkable sulfur occurrence in this area. Sublimate sulfur impregnated on the surface of sandstone presumably of flysh type, cold springs and solfataras can be seen there. The spot, however, is presumed to have little economical importance, judging from the extent of mineralization and the grade of ore.

(3) The western zone is situated in the upper Cretaceous formation mainly composed of phyllitic clayslate (spots g, h and i). The zone is characterized by the decoloration or argillization of rocks as well as the presence of cold springs and solfataras. The sulfur mineralization is relatively strong at the spot marked "i" in Fig. 7, where a decolored area, 70m by 70m, exists with a small hill, about 10m high, in the center. There are also a limonite bed, a pink mineral (alunite?) deposit, cold springs and solfataras around the hill. Impregnation of sublimate sulfur, the grade of which is S 30% at most, can be seen on the surface of the hill. The economical value of the deposit, however, does not seem very high judging from its scale.

Impregnation Deposits

There are four ore deposits of this type in the northwestern part of Anatolia, all of them being related to the Tertiary volcanic activity.

1. Ayvacik

The area is 140 km west of Baliksehir, facing the Aegean Sea. The main rock unit is a thick layer of tuff, over 100m in thickness, covered by an andesite lava, the both being unaltered

except a small zone. At the mentioned zone, the tuff is altered to a white clayey assemblage, mostly kaolin, due to sulfur mineralization. Many crystals of gypsum as well as a small quantity of sublimate sulfur are observable in the clay. The zone, however, is not so large, that is, 40m by 60m on the surface. The altered tuff is covered by a sequence of beds, 8m thick in total, in ascending order; thin lava of altered andesite, altered tuff intercalated with a bed of coaly shale, 50 cm in thickness, and nearly unaltered tuff. The coaly shale seems to have acted as the cap rock against the ore-forming fluid. The mineralization in this area, however, seems to be rather small in scale.

2. Havran

The area is 50 km west of Baliksehir and has never been prospected before. The rocks are mostly andesite lavas and are well exposed for more than 200m along a highway which was recently constructed. They are extensively altered with impregnation of iron sulfide and have clayey portions, in which opal, alunite, kaolin and other clay minerals are found. Though impregnated sulfur has not been found yet, the rock alteration appears to be favorable for sulfur mineralization. Further investigation of the altered rocks and their areal distribution would be worthy to conduct, because the observed alteration might represent a part of a more extensive alteration zone surrounding a possible hidden ore body. As far as the scale of the alteration zone is concerned, this area appears to be promising.

3. Gonen

The area is 60 km NNW of Baliksehir. A cliff composed of an altered andesite lava and an overlying river terrace deposit, with the thickness of 7m and 3m respectively, is continuously exposed for more than 200m facing a river. There are two exploration openings in the lava. The lava impregnated with iron sulfide is white at places due to intense silicification or argillization. Among numerous boulders in the fluviatile gravel bed, andesite tuff breccia, granitic rock and altered andesite lava with sublimate sulfur are found. This area, situated in steep mountains far from villages, is presently unfavorable for any profitable exploitation, but it seems worth prospecting from the evidence mentioned above.

4. Konakpinar

The area is 20 km south of Baliksehir. Altered andesite lavas widely distributed in the area underwent silicification and argillization. The silicification is widespread, while the argillization is found at a limited part, presumably 15m by 20m. The spot containing sulfur ore is in the argillized zone close to the silicified zone. The ore is of sublimate type on small fissure walls, but is of a small quantity. There is a prospecting drift, several meters in length, opened about fifty years ago. There is no pyroclastic rock in the area. From the available information, this area does not seem to be promising.

Volcanic Sedimentary Deposit

There is an ore deposit of this type in West Anatolia. The situation is close to the top of a mountain, about 500m in relative height, near Simav town, 120 km southeast of Baliksehir and is accessible by jeep. The area is surrounded by a series of steep hills composed of sericite schist and

Mesozoic limestone intruded by quartz porphyry dikes, 50m or so in width. The ore deposit occurs as a bed in an alternation of sandstone and more or less phyllitic mudstone. The alternation seems to be a lake deposit within the above-mentioned caldera-like basin and has the extent of 300m by 400m, having the maximum thickness, 15m or so, at its center with gradual decrease toward the margin. Grains of biotite and quartz, which constitute comparatively coarse-grained sandstone, were presumably derived from the quartz porphyry. The sulfur ore bed, conformable with the alternation, is 2–3m in the average thickness and is of rather high grade (S 50%+). It is well-stratified and gray to brown, occasionally being accompanied by sublimate sulfur in fissures. The country rock usually lacks sulfur with a few exceptions and often contains gypsum occurring as thin beds, 4 cm in the maximum thickness, and rarely as veinlets cutting the bedding planes. From the above-mentioned facts, the ore deposit is safely considered to be a volcanic sedimentary deposit. It is worth prospecting from its quality and scale.

Concluding Remarks

Sulfur ore deposits are roughly classified into two kinds from the genetical point of view; one is of sedimentary origin, the other being of volcanic origin. Most of the principal sulfur mines in the world belong to the former. For instance, Texas and Louisiana in the United States of America, Sicily in Italy, Conil in Spain and Bex in Switzerland have been well-known. Mines of the other kind are naturally restricted in volcanic regions such as Japan, Chile and New Zealand. Japanese sulfur mining used to be thriving, but all the deposits had been closed down one by one toward 1972 because of the industrial innovation.

Japanese sulfur ore deposits are all of volcanic origin, and further can be classified into the following three; (a) impregnation and replacement type, (b) sublimate type (including impregnation type) and (c) volcanic sedimentary type (Geological Survey of Japan, 1960, & MUKAIYAMA, H., 1970).

Turkish sulfur ore deposits are closely related to the relatively young (late Tertiary to Quaternary) volcanic activity just in the same way as those of Japan. The above-mentioned classification for the Japanese sulfur ore deposits seems to be applicable to the Turkish sulfur ore deposits as well, most of which are of (b), accompanied by two examples of (a) and (c). The ore deposit at Keciborlu, strictly speaking, is of an intermediate type between (a) and (b). Japanese sulfur ore deposits are mostly situated at the hill-side or the foot of the late Tertiary or Quaternary strato-volcanoes composed almost exclusively of pyroxene andesites. They are rarely related to rhyolite or dacite, but being of sublimate type of small scale. The ore deposit at Keciborlu where the deposit associates with limestone and serpentinite is unusual for Japanese geologists. As to the genetical processes, however, there may be no basic difference between Turkish and Japanese sulfur ore deposits.

Acknowledgements

The authors express their hearty thanks to Dr. Sadrettin ALPAN, General Director of the MTA, for his permission to publish this paper. Also they are grateful to Dr. Ismail SEYHAN, Director of the Department of Industrial Raw Materials of the same Institute, for his helpful suggestions and encouragement. They are indebted to Mr. Gungor MEHMET, Mr. Mehmet

OKUT, Mr. Akay FADIL and Mr. Baki AKCA, Senior Geologists of the MTA, for their co-operation in the field.

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Besides there are some unpublished reports concerning sulfur ore deposits stored in the MTA.

トルコの硫黄鉱床

太田 良平・間遠 治孝

要 旨

ケチボール鉱山はトルコ国唯一の硫黄鉱山で，精製硫黄の月産は約 3,000 t，同国年間需要量の 5 分の 3 を供給しており，白亜紀石灰岩層およびこれを貫く蛇紋岩の上に，不整合に載る火山砕屑岩層の中に胚胎した鉱染交代鉱床で，この火山砕屑岩層の上に衝上断層を隔てて横たわる前記両岩を冠岩としており，鉱体の規模は大きくない．ほかにトルコ全土にわたり鉱染鉱床 4 カ所，昇華鉱床 6 カ所，火山性堆積鉱床 1 カ所あり，いずれも探鉱されたことがあるが規模は小さい．世界で主な硫黄鉱床はほとんど堆積源であるが，トルコの硫黄鉱床は火山源であり，日本のそれに類似する．

(受付：1974年12月24日；受理：1975年 7 月23日)