A REVIEW OF THE MINERALOGY OF THE TURKISH BORATE DEPOSITS

by

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Summary

The known borate deposits of Turkey were deposited in lacustrine sediments of Tertiary age during periods of volcanic activity which commenced in the early Tertiary period and continued at least to the beginning of the Quaternary. All Turkish borate deposits appear to be associated with volcanic activity and they have been classified as deposits related to volcanic activity.

Although colemanite, a very common calcium borate, is the predominant mineral in all borate districts apart from Kirka, the detailed mineralogy of the Turkish borate deposits varies considerably. Other principal borate minerals are ulexite (sodium calcium borate) and borax (sodium borate). Borax occurs only at Kirka. Tertschite occurs in the Bigadiç deposits and pandermite is also restricted appearing only in the Bigadiç and Sultançayiri deposits.

Turkey has made recent rapid strides towards rivalling the U.S.A. as the world's leading producer of borates. Boron and borate minerals find extensive uses in today's modern industries.

Introduction

This paper adds further to the knowledge of borate minerals in Turkish deposits reported by a few previous workers, namely Murdock (1958), Wendel (1962), Özpeker (1969) and finally Brown and Jones (1971). Since then, Inan (1973) and Helvaci (1977) have carried out detailed research work on the Kirka and the Emet deposits respectively, which has resulted in new mineralogical discoveries and contributed considerably to the understanding of the borate minerals and deposits in Turkey.

Although boron is one of the rarer and more unevenly distributed elements in the Earth's crust, there are extraordinary concentrations of boron on an industrial scale in some localized areas. Borate minerals are formed in various environments and in very different conditions. The most important economic deposits are very closely related to the Tertiary volcanic activity in orogenic belts. They are situated close to converging plate margins; characterized by andesitic-rhyolitic magmas; arid or semi-arid climates; and non-marine evaporite environments. All Turkish, United States, South American and many other commercial borate deposits are non-marine evaporites associated with volcanic activity.

The known borate deposits of Turkey occur in Western Anatolia, south of the Marmana Sea, within an area roughly 300 km east-west by 150 km north-south. They are located mainly in the following districts:- M. K. Pasha, Bursa province; Susurluk and Bigadiç, Balikesir province; Emet, Kutahya province; and Kirka, Eskisehir province (text-fig. 1). Today, however, borate mining in Turkey is confined to the Emet, Kirka and Bigadiç districts.

The known borate deposits of Turkey were formed in the lacustrine sediments of Tertiary age during periods of volcanic activity which commenced in the early Tertiary period and continued at least to the beginning of the Quaternary. Although the lithology of the borate deposits shows some differences from one deposit to another, they are, generally, interbedded

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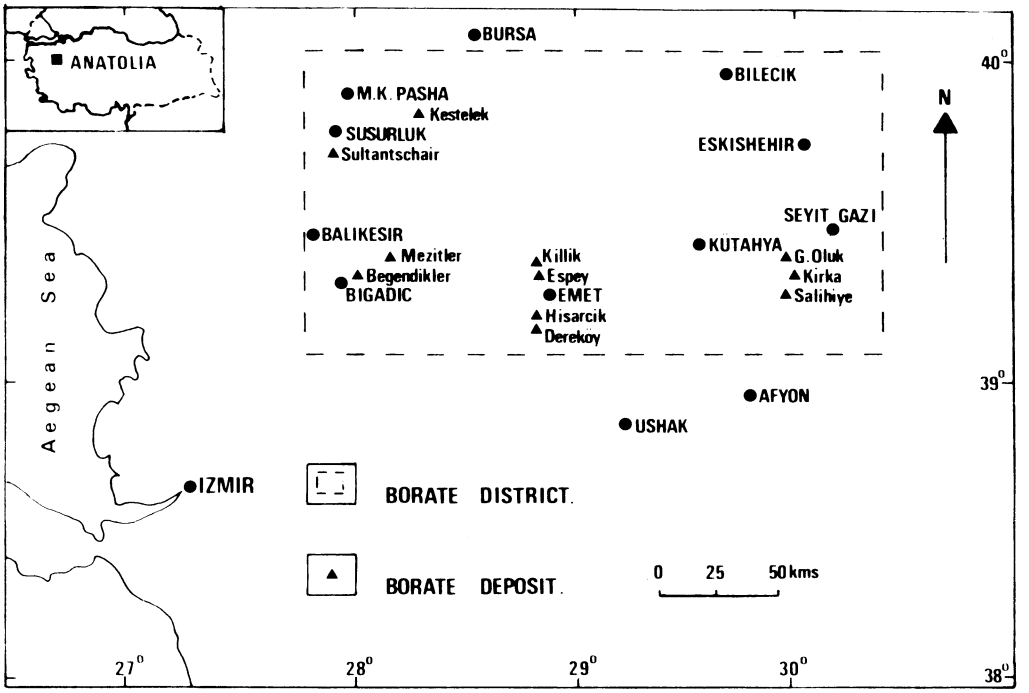
pp. 257-270, 1 text-fig. Plates 18, 19, 20.



Text-fig.1. Borate districts in Anatolia W. Turkey (reproduced with permission of the Institution of Mining and Metallurgy)

with conglomerate, sandstone, tuff, clay, marl and limestone. Sediments in the borate lakes often show clear evidence of cyclicity. Borate minerals were deposited in separate or possibly interconnected lake basins under arid or semi-arid climatic conditions.

Pyroclastic and volcanic rocks of rhyolitic, dacitic, trachytic, andesitic and basaltic composition are intercalated with these lacustrine sediments. The existence of volcanic rocks in every borate district suggests that volcanic activity may have been necessary for the formation of borates. Much of the sediment in the borate basins seems to have been derived from volcanic terrain.

In general, the dip of the Tertiary sediments, interbedded with borates, vary from nearly horizontal to over 30°, but they are intensively dislocated by NE-SW and NW-SE-trending gravity faults. This structure is strikingly reflected in a stepwise topography. The predominant faults are normal, with dips that range from 30° to vertical. Thermal springs, which at present deposits travertine, are widespread in some of the deposits. The total Tertiary sedimentary thickness varies from one deposit to another, probably because of deposition in a chain of interconnected lakes, and exceeds maximum 750 m in the Emet deposits. The extreme thickness of the borate zones at Emet and Kirka indicates that there have been somewhat different conditions existing at the time of the formation of these deposits. The depositional basins of borate deposits, according to present knowledge, are all elongated, the long axis usually being north-south.

The borate deposits differ in detail from each other but have the following features in common:-

(a) They are restricted to Tertiary lacustrine sediments deposited in a non-marine environment under arid or semi-arid climatic conditions.

(b) They were apparently deposited in sedimentary intermontane basins of limited extent in regions where fresh-water limestone deposition was widespread both before and after borate formation.

(a) In addition to borates these basins were the repositories for clastic sediments, i.e. conglomerate, sandstone, clay, marl and tuff, much of which are of volcanic origin.

(b) Although the lithology of the borate deposits shows some differences from one to another, sediments in the borate lakes often show clear evidence of cyclicity.

(c) All Turkish borate deposits appear to be associated with volcanic activity and they were classified by Aristarain and Hulbut, 1972 as deposits related to volcanic activity.

(f) Borate occurrences are associated with volcanic rocks; both intrusive and extrusive volcanic rocks are common in the neighbourhood of the borate basins.

(g) More typical evaporite minerals, such as halite and trona, are not found in Turkish borate deposits.

(h) The palaeogeographic scenario seems to have consisted of shallow lakes fed partly by hot springs and partly by streams which carried sediments from the surrounding volcanic, limestone and basement terrain. The rocks which may have been exposed in the catchment areas appear to be in restricted and closed basins.

Minerology

The unique character of the borate deposits in Turkey indicates that the conditions of formations of these deposits are different from those that lead to the formation of the more typical non-marine evaporite deposits. Although colemanite, a very common calcium borate, is the predominent mineral in all borate districts apart from Kirka, the detailed mineralogy of the Turkish borate deposits varies considerably, but they may be roughly classified as follows:

1. Ca borate deposits (Emet, Bigadiç, Kestelek, Sultançayiri).
2. Na borate deposit (Kirka).

Borate minerals hitherto recorded from Turkish deposits are mainly Ca; Ca-Mg; Na and Mg borates. A rare Sr borate has been found at Kirka (Baysal, 1972) and Ca-As and Sr borates have been reported from the Emet district (Helvaci and Firman, 1976 and Helvaci, 1977). Table 1 gives the complete list of borate minerals from the Turkish deposits and shows that each deposit has its characteristic assemblage of minerals.

Generally, borate minerals are associated with calcite, dolomite, gypsum, celestite, realgar, orpiment and sulphur. The mineralogy of the Emet borate deposits is unique among the other Turkish borate deposits, because of unusual occurrences of Ca-As and Sr borates and the high content of sulphur, realgar, orpiment and celestite.

Borate and non-borate minerals, according to their chemical composition and their mineralogical relationships with each other in the Turkish deposits, may be divided into ten groups namely the calcium borates, the sodium-calcium borates, the sodium borates, the magnesium-calcium borates, the magnesium borates, the strontium borates, the silicon-calcium borates, the complex borates, the compound borates and the non-borates.

Borate minerals within each group have nearly the same chemical composition, differing from one to another principally the amount of water of hydration in the structure.

Mineral descriptions

Calcium borates

Inyoite ($2CaO.3B_2O_3.13H_2O$)

Inyoite occurs locally at some of the mines in the Kirka and Bigadiç deposits. It is found as intergrown crystal masses, discrete tabular crystals and crystal groups, colourless to white (Plate 18, fig.1). A few of the crystals are 2.5 cm or larger, but most are microscopic in scale and have been altered. Some of the inyoite in the deposits had altered to meyerhofferite and/or colemanite. Sometimes it occurs as clear, coarse-grained, euhedral aggregates. It is clearly associated with meyerhofferite, colemanite and ulexite.

Table 1 Borate minerals found in the Turkish borate deposits

Mineral Name	Oxide Formula	B_2O_3 Content wt%	Deposit	References
Inyoite	$2CaO.3B_2O_3.13H_2O$	37.62	Kirka, Bigadiç	Meixner (1953b)
Meyerhofferite	$2CaO.3B_2O_3.7H_2O$	46.72	Emet, Kirka, Bigadiç	Meixner (1953b); Helvaci *et al.*, (1976)
Colemanite	$2CaO.2B_2O_3.5H_2O$	50.81	Emet, Kirka, Bigadiç Kestelek	Meixner (1952)
Tertschite	$4CaO.5B_2O_3.20H_2O$	37.32	Bigadiç	Meixner (1952)
Pandermite (= priceite)	$4CaO.5B_2O_3.7H_2O$	54.59(49.84)	Bigadiç, Sultançayiri	Schlüter (1928)
Ulexite	$Na_2O.2CaO.5B_2O_3.16H_2O$	42.95	Emet, Kirka, Bigadiç	Meixner (1953b); Helvaci *et al.* (1976)
Borax	$Na_2O.2B_2O_3.10H_2O$	36.51	Kirka	Inan (1972); Baysal (1972)
Tincalconite	$Na_2O.2B_2O_3.5H_2O$	47.80	Kirka	Helvaci (1977)
Kernite	$Na_2O.2B_2O_3.4H_2O$	51.02	Kirka	Helvaci (1977)
Hydroboracite	$CaO.MgO.3B_2O_3.6H_2O$	50.53	Emet, Kirka, Bigadiç	Özpeker (1969); Helvaci (1974)
Inderborite	$CaO.MgO.3B_2O_3.11H_2O$	41.49	Kirka	Baysal (1973)
Inderite	$2MgO.3B_2O_3.15H_2O$	37.32	Kirka	Inan (1972); Baysal (1973)
Kurnakovite	$2MgO.3B_2O_3.15H_2O$	39.89	Kirka	Inan (1973); Baysal (1973)
Tunellite	$SrO.3B_2O_3.4H_2O$	54.32	Emet, Kirka	Baysal (1972); Helvaci *et al.*, (1976)
Veatchite (*senso lato*)	$4SrO.11B_2O_3.7H_2O$	58.16	Emet	Helvaci (1974); Helvaci *et al.*, (1976)
Howlite	$4CaO.5B_2O_3.2SiO_2.5H_2O$	44.49	Bigadiç	Özpeker (1969)
Terruggite	$4CaO.MgO.6B_2O_3.As_2O_5$ $20H_2O$	32.76	Emet	Negro *et al.*, (1973) Helvaci *et al.*, (1976)
Cahnite	$4CaO.B_2O_3.As_2O_5.4H_2O$	11.69	Emet	Helvaci *et al.*, (1976)

Meyerhofferite ($2CaO.3B_2O_3.7H_2O$)

Meyerhofferite is found as small grey-bluish coloured nodules up to 8 cm in diameter associated with colemanite and inyoite and sometimes with ulexite. It occurs as nodules of coarsely crystalline radiating crystals intergrown with clay at the margins. Small vughs in the centre of the nodule contain delicate acicular crystals (Plate 18, fig. 2), which are also meyerhofferite. It either forms by direct precipitation from calcium borate solutions or by the dehydration of inyoite, in the Turkish deposits.

Colemanite ($2CaO.2B_2O_3.5H_2O$)

Colemanite is by far the commonest mineral deposits and for this reason some occurrences are usually referred to commercially as colemanite deposits. It occurs in many different forms ranging from minute stellate clusters of crystals in clay to ovoid nodules up to 50 cm in diameter and as continuous layers. The individual crystals which make up the nodules are colourless, grey, pink and dark blue. Among the commoner habits are nodular forms with radiating structures (Plate 18, fig. 3); massive granular colemanite (fig. 6); disseminiated crystals, often stellate, in a clay matrix (fig. 5); fibrous layers surrounding nodules (fig. 6); thin layers interbedded with clay, sometimes brecciated; and vugh fillings (fig. 7); bladed euhedral crystals (fig. 4).

Nodules are by far the commonest form of colemanite, but these nodules exhibit a large variety of shapes and sizes. There is a tendency for the smaller nodules to be spherical and the larger ones to be ovoid. Some, irrespective of size, contain vughs; which sometimes contain a liquid; others have a core of granular colemanite which is coarsely crystalline and second-generation in origin. Closer inspection reveals that these nodules grew in successive stages, each layer being separated by a thin discontinuous veneer of clay. Later generations of colemanite crystals radiate from separate centres of nucleation on the original nodule.

Often it is difficult to identify all stages of nodule growth, but judging from the presence of included clay, it is clear that these nodules formed within the clays and tuffs below the sediment/water interface and probably continued to grow as the sediments were compacted in the Emet deposits (Helvaci and Firman, 1976 and Helvaci, 1977). Colemanite also results from the breakdown of ulexite or the dehydration of inyoite in the Kirka, Bigadiç and Kestelek deposits (Inan *et al.*, 1973; and Özpeker, 1969).

Tertschite ($4CaO.5B_2O_3.20H_2O$)

Terschite is found only in one locality in the Bigadiç deposits (Meixner, 1952). It is white, contains very fine fibres, shines like silk and has a similar appearance to ulexite. Sometimes it shows an earthly structure and its rare occurrence makes this mineral unique among the other borate minerals.

Pandermite (= priceite) ($4CaO.5B_2O_3.7H_2O$)

Pandermite occurs at the Sultançayiri and Bigadiç deposits. It was named after the place where it was found; then it was discovered that pandermite was identical to priceite described from Oregon, U.S.. The identity of pandermite with priceite has been established by chemical and optical studies. Pandermite is found as nodules and masses up to a ton in weight underlying beds of gypsum and clay. It appears white in colour, compact and sometimes resembles limestone.

It alters to colemanite and calcite and is associated with colemanite, gypsum and calcite.

Sodium-calcium borates

Ulexite ($Na_2O.2CaO.5B_2O_3.16H_2O$)

Ulexite is the only mineral of the Na-Ca borate series found in the deposits. It occurs at three levels and always as massive and cauliflower-like nodules in the Emet deposits (Plate 18, fig. 8); fibrous, cone, rosette, 'cotton ball' and columnar textures are observed

in the Kirka deposit (Plate 19, fig.1). Sometimes, very thin fibrous ulexite crystals growing on top of the massive and cauliflower-like ulexite nodules have been observed and cauliflower-like nodules composed of randomly orientated crystals, 1 - 5 cm long, form independent layers up to a few metres in thickness.

Ulexite is commonly associated with colemanite and hydroboracite in the Emet deposits, but no alteration to colemanite or from any other mineral has been observed. It is usually very soft. The purest forms of ulexite are white, but many are grey due to the nodule growing in the clay. Thus, like colemanite and meyerhofferite, ulexite nodules appear to have developed within and not on the sediments (Helvaci, *et al.*, 1976; Helvaci, 1977).

Ulexite is commonly associated with borax, colemanite and inyoite in borate layers, and with kurnakovite and tunellite in clay layers in the Kirka deposit. Cone and rosette-shaped aggregates of ulexite are found as pseudomorphs after borax on the borax layers at borax-clay interfaces in the Kirka deposit (Inan *et al.*, 1973). Ulexite showing fibre-optical properties has not been recorded from the Turkish deposits, because ulexite commonly appear to be impure due to the clay contents.

Sodium borates

Borax ($Na_2O.2B_2O_3.10H_2O$)

Borax is by far the most abundant borate mineral found in the Kirka deposit (Inan, 1972 and Inan *et al.*, 1973), and for this reason it is usually called a borax deposit. It is restricted to the Kirka deposit. The highest concentrations of borax are in the central part of the deposit. Fresh, pure borax is colourless and transparent (Plate 19, fig. 2), but in places, where it is fine-grained and interbedded with clay, it is light pink, yellowish-orange or grey due to fine inclusions of foreign material. Borax occurs mainly as subhedral and anhedral crystals usually 1 mm - 10 mm in size. Large masses of subhedral borax crystals are often found in the cavities created after burial. Sometimes it is also observed as disseminated individual crystals in the clay matrix and as borax-clay breccia. Some very large crystals, up to 10 m in length and 2 m broad, cutting across the bedding, have been observed (Inan *et al.*, 1973).

Borax occurs chiefly (Plate 19, fig.3) in almost monomineralic zones interbedded with clay and associated with tincalconite and fibrous or "cotton ball" ulexite. In many places tincalconite forms a thin film on the exposed part of borax crystals and borax shows a transformation into ulexite at borax-clay interfaces.

Tincalconite ($Na_2O.2B_2O_3.5H_2O$)

Tincalconite is also restricted to the Kirka deposit and does not form independent crystals in this deposit but occurs only as an alteration product of borax (Plate 19, fig. 4) and kernite (Plate 19, fig. 5). The fine microscopic crystals of tincalconite develop very rapidly on borax or kernite crystals in contact with atmosphere, in a matter of days depending on the humidity and temperature (Inan *et al.*, 1973).

Kernite ($Na_2O.2B_2O_3.4H_2O$)

Kernite has a restricted distribution and is found only at one locality in the underground workings of the Kirka deposit. New kernite crystals may be found when the underground workings advance. It is developed in the deeper part of the sodium borate body at Kirka. (Helvaci, 1977).

It occurs as colourless, transparent but sometimes white elongated needle-shaped, or group of needle-shaped, crystals which are surrounded by a zone or borax. Individual crystals vary in their length, which is up to 10 cm. Kernite alters by dehydration to white tincalconite which occurs as fine-grained coatings on kernite crystals that have been exposed to the atmosphere (Plate 19, fig. 5).

Magnesium-calcite borates

Hydroboracite ($CaO.MgO.3B_2O_3.6H_2O$)

Hydroboracite is found throughout all the major deposits and occurs sporadically at different horizons and in clay layers. It forms small clusters (nodules) in which radiating needle-shaped crystals, 0.5 - 5 cm, are randomly orientated (Plate 19, fig. 6). Radiating needle-shaped crystals of hydroboracite intersect with each other and groups of them show a conical appearance (Plate 19, fig. 7).

Sometimes, it forms thin layers within the interbedded clay. In the thin section, the needle-shaped crystals of hydroboracite have a fibrous texture. This mineral is usually white, but sometimes it appears yellowish in colour due to the presence of realgar and orpiment in the Emet deposits (Helvaci, 1977). It is associated with colemanite and ulexite and sometimes with tunellite.

Inderborite ($CaO.MgO.3B_2O_3.11H_2O$).

Inderborite occurs very rarely and is restricted to the Kirka deposits. It is found intergrown with kurnakovite and ulexite, especially with the former in the deposit (Baysal, 1973). It occurs in the form of thick prismatic crystals which can reach a few centimeters in length. The inderborite crystals are often in white colour, semitransparent and they show glassy or weak pearly luster on the cleavage faces. Colourless and transparent crystals are also found. It is clearly associated with kirnakovite, ulexite and calcite.

Magnestium borates

Inderite ($2MgO.3B_2O_3.15H_2O$)

Inderite is described from the Kirka deposit and has a restricted distribution (Baysal, 1973). It has been found with kurnakovite only in the upper part of the borate zone in the deposit. Inderite commonly occurs either as thin rods and needles or as radial and spherulitic aggregates which are usually associated with clay and kurnakovite crystals. The inderite crystals are 1 - 2 cm long and 1 - 2 mm wide. The crystals are colourless, transparent and have a glassy luster which is vitreous to pearly on cleavage planes, dull and greasy on irregular surfaces. Sometimes inderite appears grey in colour, because it often contains small amounts of clay. It is commonly found in close association with kurnakovite.

Kurnakovite ($2MgO.3B_2O_3.15H_2O$)

Kurnakovite is found in the upper part of the Kirka deposit and forms a non-continuous layer in the clay just above the main borate body. The kurnakovite layer consists largely of 1 - 20 cm long individual, colourless grey or sometimes pink, elongated, euhedral crystals (Plate 19, fig. 8) and crystal aggregates. Its distribution is similar to that of inderite but it is much more common. It coexists frequently with ulexite, inderite and tunellite and less frequently with borax. (Inan *et al.*, 1973).

Strontium borates

Tunellite ($SrO.3B_2O_3.4H_2O$)

Tunellite has a restricted distribution and has been found only in the lower part of the borate zone in the Emet deposits and in the clay layers in the Kirka deposit. It occurs in very small amounts.

Tunellite commonly occurs either as individual flattened crystals (Plate 20, fig. 1), 1 - 5 cm in length, or as thin tabular-shaped crystals which have nucleated on (but not replaced) ulexite. Pure flattened tunellite crystals are colourless, transparent and have perfectly developed cleavages parallel to flattened surfaces, which resemble muscovite flakes (Plate 20, fig. 1). Alternatively tunellite occurs as small white nodules with radiating structures, which have

apparently grown in the interbedded clays (Plate 20, fig. 2). In the Emet deposits, it is associated with ulexite and colemanite whereas in the Kirka deposit, it coexists with hydroboracite and ulexite. This mineral was described from the Kirka deposit by Baysal (1972) and from the Emet deposits by Helvaci *et al.*, (1976), but has not been identified in any other Turkish borate deposits.

Veatchite (*sensu lato*) ($4SrO.11B_2O_3.7H_2O$)

Veatchite is very rare, occurring sporadically at one horizon in the northern basin of the Emet deposits. It appears as a very pure white mineral often with clay inclusions, with small (up to 2 cm in diameter) and large (up to 6 cm in diameter) nodules made up of little needle-shaped crystals. Sometimes very small nodules are associated together and show mammilary appearance (Plate 20, fig. 3).

Veachite (*sensu lato*) occurs as felted masses of very small crystals which are sufficiently curved to preclude a positive distinction between veatchite and p-veatchite (Braitsch, 1959) by single crystals X-ray examination. Due to the absence of suitable crystals, the single crystal study has failed to distinguish between veatchite and p-veatchite (Helvaci, 1977).

This mineral is usually associated with colemanite. Field and textural evidence shows that this mineral replaces colemanite and is not associated with the other Sr borate, tunellite. It was first recorded from the Turkish borate deposits by Helvaci (1974). (Helvaci and Firman (1976)).

Silicon-calcium borates

Howlite ($4CaO.5B_2O_3.2SiO_2.5H_2O$)

Howlite has a very restricted distribution and has been found only in the Domaz mine of the Bigadiç deposits (Özpeker, 1969). It occurs as compact nodular masses, internally dense and structureless and resembles unglazed porcelain; sometimes chalk-like, earthy, scaly, or with a slaty structure. It is white in colour and translucent in thin splinters, and is associated with colemanite.

Complex borates

Teruggite ($4CaO.MgO.6B_2O_3.As_2O_5.20H_2O$)

Teruggite is rare, occurring sporadically at one horizon in the southern basin of the Emet deposits, as very pure white, powdery potato-shaped nodules containing countless minute white euhedral crystals. The nodules of teruggite range from 2 to 10 cm in diameter (Plate 20, fig. 4).

Occasionally these powdery potato-shaped teruggite nodules contain very small spherulites of cahnite (Plate 20, fig. 5). This is the first record of this type of teruggite and cahnite occurrence from borate deposits. The crystal structure of teruggite from the Emet deposits was described by Negro, Kumbasar and Ungaretti (1973).

The sporadic occurrence of teruggite and cahnite, compared with the almost universal distribution of arsenic sulphides in the Emet deposits, suggests that borates developed in areas in which the brines were difficient in sulphides (probably H_2S) which would have otherwise precipitated the arsenic as realgar instead of arsenic bearing borates. Teruggite is associated with cahnite and colemanite.

In the thin section, the crystals of teruggite are colourless, prismatic-shaped and are greatly elongated along the C axis. These crystals usually appear very small and needle-shaped. Occasionally spherulites of cahnite occur in the teruggite masses and fibrous crystals of cahnite show a radial texture (Plate 19, fig. 6).

Compound borates

Cahnite ($4CaO.B_2O_3.AS_2O_5.4H_2O$)

Cahnite, a very rare borate mineral, was first recorded from Franklin, New Jersey by Palache, *et al.*, (1927), appearing in the cavities of axinite veinlets associated with pegmatites cutting the main ore-body. Later discoveries of this mineral are associated with scarn zones as reported from the Klodeborg mine, Arendal, Norway, by Bugge (1951) and from Eastern Siberia, U.S.S.R. by Malinko (1966), Cahnite was also recorded by Embrey (1960), from a cavity in dark grey leucitic lava at Capo di Bove, Rome, Italy, where it is found on calcite associated with phillipsite and chabazite.

Cahnite was first recorded from the Emet borate deposits by Helvaci and Firman (1976). It had not hitherto been identified from borate deposits. In the Emet borate deposits, cahnite occurs as very small spherulites in powdery potato-shaped teruggite nodules in the southern area (Plate 20, fig. 6), and as a coating on euhedral colemanite crystals in vughs in colemanite nodules in the northern area (Plate 20, fig. 7). Cahnite is rare; occurring sporadically only at one horizon. It is associated with colemanite and calcite in the northern basin, whereas it is associated with teruggite and colemanite in the southern basin.

The spherulites of cahnite are generally very small, rarely exceeding 2 mm in diameter and occurring usually singly, but occasionally two or three coalesce together (Plate 20, fig. 8). Cahnite is white and light brown in colour with a notably glassy lustre. In the thin section, the cahnite spherulites contain needle-shaped and fibrous crystals which often show a radial texture (Plate 20, fig. 6).

Non-borates:

A number of non-borate minerals associated with borates occur in the borate zone of the deposits. Generally borate minerals are associated with calcite, dolomite, gypsum, celestite, realgar and orpiment. The last two minerals along with celestite, native sulphur and gypsum do not occur in the Kirka deposit whereas these minerals are abundant throughout the Emet deposits. Dolomite does not occur in the Emet deposits. Calcite, quartz and chert are common in all the deposits. Gypsum and calcite are the common non-borate minerals occuring in the other Turkish borate deposits.

The occurrence of the clay minerals (such as montmorillonite and illite) in all deposits, and sulphide and sulphate minerals in the Emet deposits is ubiquitous.

The economic importance of borate minerals:

Turkey is currently the second largest producer of borate minerals and has the world's largest reserves. The level of output is rapidly rising towards that of the USA and has been continuously expanded to meet increasing demands of world consumers. Already Turkey is the major world producer of colemanite much of which comes from the Emet Valley and further increases, particularly of borax from Kirka, are likely to lead to Turkey dominating the world markets. Proved and probable reserves of all boron minerals are vast in relation to output and are measured in hundreds of years supply, even by the most conservative estimates.

The possible large use of boron and borates minerals in different types of industrial products will rapidly increase the demand of borates in crude and manufactured forms such as boric acid and borax salts. Production of crude borates in Turkey will relatively expand enlarging demand and supply relationships in the whole world. Production and consumption of crude and refined boron products has grown impressively in recent years and because of borates' diversity of use, even stronger growth is anticipated in the 1970's. The growth of consumption, reflecting the fact that the largest markets are in household and industrial cleaners and the glass and ceramic industries, is closely related to the growth of population and the use of durables, and can fluctuate.

Boron products are used in a surprisingly wide variety of industries; literally hundreds of products, from fibre-glass and pharmaceuticals to fertilizers and photographic chemicals

contain the same basic ingredient - borax. The requirements of the glass, enamel and other traditional user industries has tended to rise steadily with increased population, with a rising standard of living and with industrial development in general, but the recent quite rapid expansion of the boron products industry owes much to the growth shown by sodium perborate, glass fibre and nylon.

Boron is a versatile and useful element used mainly in the form of its many compounds, of which borax and boric acid are most well known. Boron compounds are used extensively in the glass and ceramics industries, where their low melting points and excellent fluxing properties are utilized. Their properties are also advantageous in brazing, welding, soldering and refining.

Borax and boric acid are used in soaps, cleaners, and detergents because of their bactericidal properties, easy solubility in water, and excellent water-softening properties. Their mild alkalinity in water and germicidal properties make them useful in toothpaste, mouthwash, and eyewash preparations. Water solutions of borax are used in dyeing leather and textiles, in cleansing hides and skins, in plasters and paints, to prevent mildew and give high gloss to starches, and to prevent mold on leather, textiles, and citrus fruits. In agriculture, borax is added to fertilizers to supply boron as an essential plant nutrient. Boron compounds are also used to control weeds.

Boron compounds, being excellent fluxing materials, are especially useful in welding, soldering, brazing metals and in metal refining and are also added to alloy steels to increase hardness. Some elemental boron is used as a deoxidizer in nonferrous metallurgical reactions, as a grain refiner in aluminium, as a thermal neutron absorber in atomic reactors, in delayed action fuses, as an ignitor in radio tubes, and as a coating material in solar batteries.

Compounds of boron such as boron carbide, titanium boride, tungsten boride and boron nitride are among the hardest substances known. The cubic boron nitride known by the trade name Borazon is harder than diamond and has a greater thermal stability. Boron nitride is also useful as a thermal insulator and as a mould lubricant in glass manufacture. Boron carbide is used in the manufacture of abrasion-resistant parts of spray nozzles, bearing liners, and furnace parts; in the atomic energy field as nuclear reactor control elements and radiation shields; and as an abrasive for ultrasonic grinding and drilling. Boron trichloride is used as a catalyst, synthesis intermediate and extinguishing agent whereas boron trifuloride is used as a catalyst for many organic reactions.

Organic boron compounds such as borate esters are finding greater use as dehydrating agents, synthesis intermediates, special solvents, sources of boron for catalysts, plasticizers, and adhesion additives for latex paint, and fire retardants in plastics and protective coatings. Boron compounds such as diborane (B_2H_6), pentaborane (B_5H_8), decaborane ($B_{10}H_{14}$), and alkyl boranes are potential jet and rocket fuels.

New discoveries and the rapid increase in the living standard of huge sectors of society the world over will create greater demands for wonderful boron compounds. Interest in borate minerals and deposits will grow accordingly.

The above account on the use of borate minerals is based on Miller (1965) and Aristrain and Hurlbut (1972).

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EXPLANATION FOR PLATES 18 and 19

Plate 18, fig. 1. Large inyoite aggregate showing tabular crystals.

" fig. 2. Meyerhofferite nodule showing coarsely crystalline radiating crystals and vugh in the centre, containing acicular crystals, Espey underground mine, Emet.

" fig. 3. Section of colemanite nodule showing radiating structure with clay injection inbetween colemanite crystals, vugh in the centre filled with euhedral colemanite crystals and clay covering the outer edge of the nodule. Killik underground mine, Emet.

" fig. 4 Cluster of bladed euhedral colemanite crystals from Espey underground mine, Emet.

" fig. 5. Semi-developed stellate colemanite crystals in a clay matrix showing radiating groups of colemanite crystals, Killik underground mine, Emet.

" fig. 6. Massive colemanite surrounded by the layer of fibrous colemanite. Clay associated with colemanite is montmorillonite, Espey underground mine. Emet.

" fig. 7. Euhedral colemanite crystals filling vughs and cavities, Espey underground mine, Emet.

" fig. 8. Occurrence of massive cauliflower-like ulexite nodule with silky appearance at the Killik mine, Emet.

Plate 19, fig. 1. Occurrence of columnar ulexite at the Kirka deposit.

" fig. 2. Colourless and transparent borax body interbedded with clay, Sarikaya underground mine, Kirka.

" fig. 3. Borax (grey) interbedded with very thin clay bands (light), Sarikaya underground mine, Kirka.

" fig. 4. Borax crystals with tincalconite occurring as a thin film coat on surface, Sarikaya opencast mine, Kirka.

" fig. 5. Kernite crystals with tincalconite occurring as a thin fine-grained coat on upper surface, Kirka.

" fig. 6. A small cluster of hydroboracite showing radiating needle-shaped crystals which are randomly orientated, Sarikaya locality, Emet.

" fig. 7. Radiating crystals of hydroboracite intersecting with each other and groups of them showing a conical appearance, Killik locality, Emet.

" fig. 8. Well developed kurnakovite crystal from Kirka deposit.

EXPLANATION FOR PLATE 20

Plate 20, fig. 1. Individual flattened tunellite crystals showing perfectly developed cleavages and resembling muscovite flakes, Espey mine, Emet.

" fig. 2. Small white tunellite nodules with radiating structures growing in the interbedded clays, Killik mine, Emet.

" fig. 3. Very small nodules of a veatchite mineral associated together showing mammillary appearance, Killik mine, Emet.

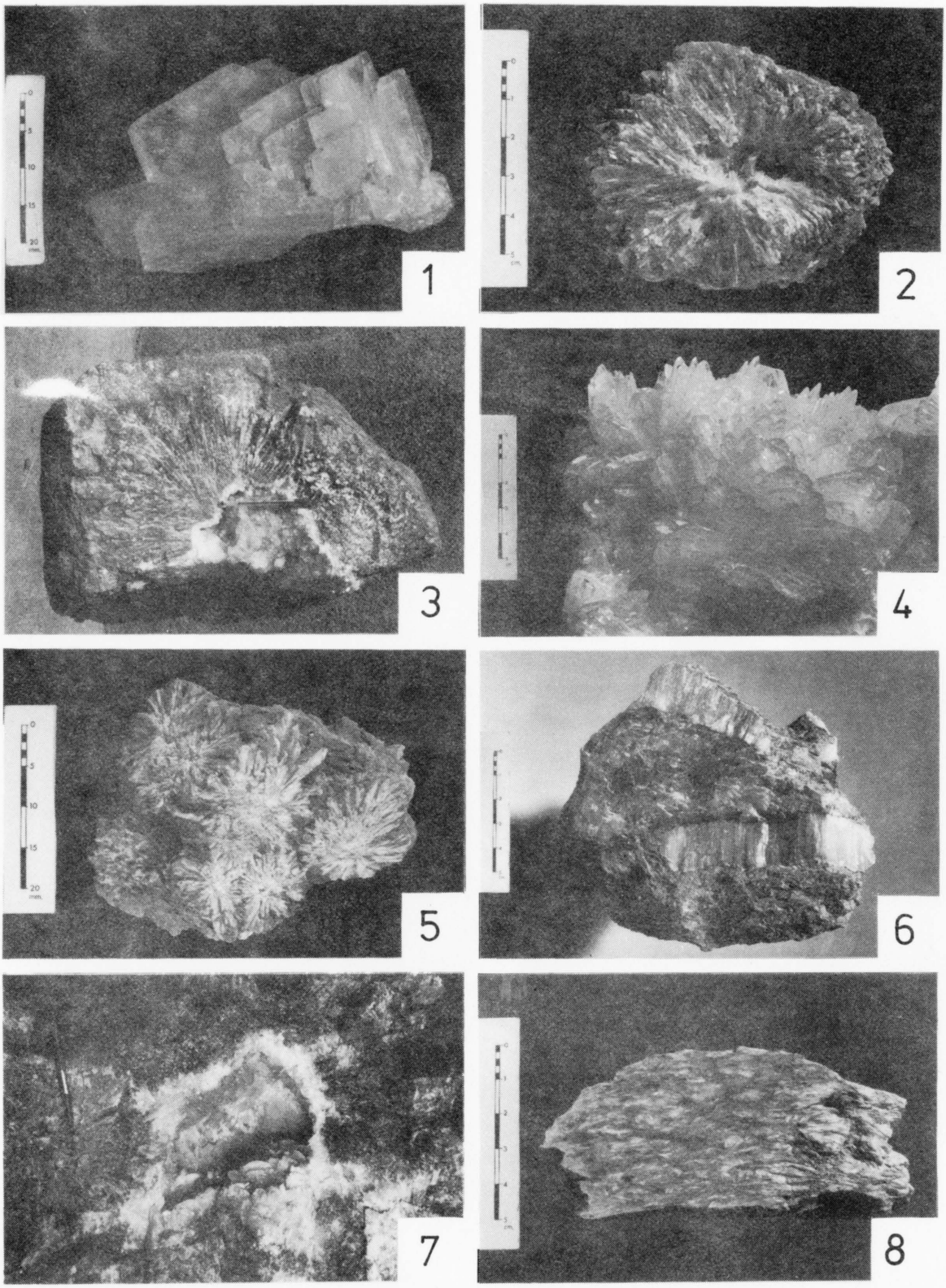
" fig. 4. A very pure white and powdery potato-shaped teruggite nodule, with rare clay inclusions, Kapikaya locality, Emet.

" fig. 5. A powdery potato-shaped teruggite nodule containing very small spherulites of cahnite. Note also countless minute white euhedral crystals of teruggite, Kapikaya locality, Emet.

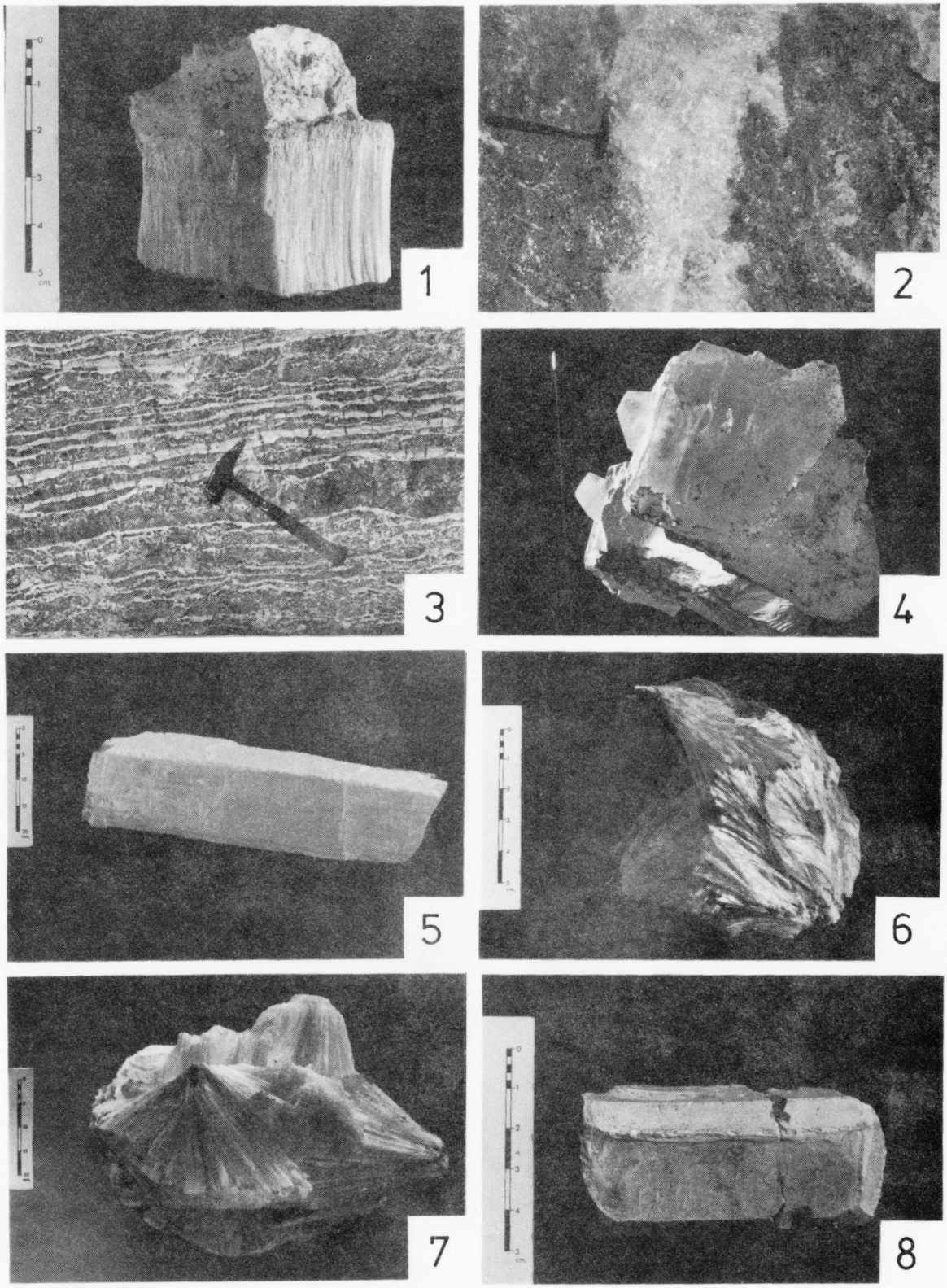
" fig. 6. A spherulite of cahnite occurring in the teruggite masses, Emet. Plane polarized light, X10.

" fig. 7. Cahnite occurring as a coating on euhedral colemanite crystals, Espey locality, Emet.

" fig. 8. Spherulites of cahnite which rarely exceed 2 mm in diameter, Kapikaya locality, Emet.



Helvaci - Turkish borates (explanation p. 269).



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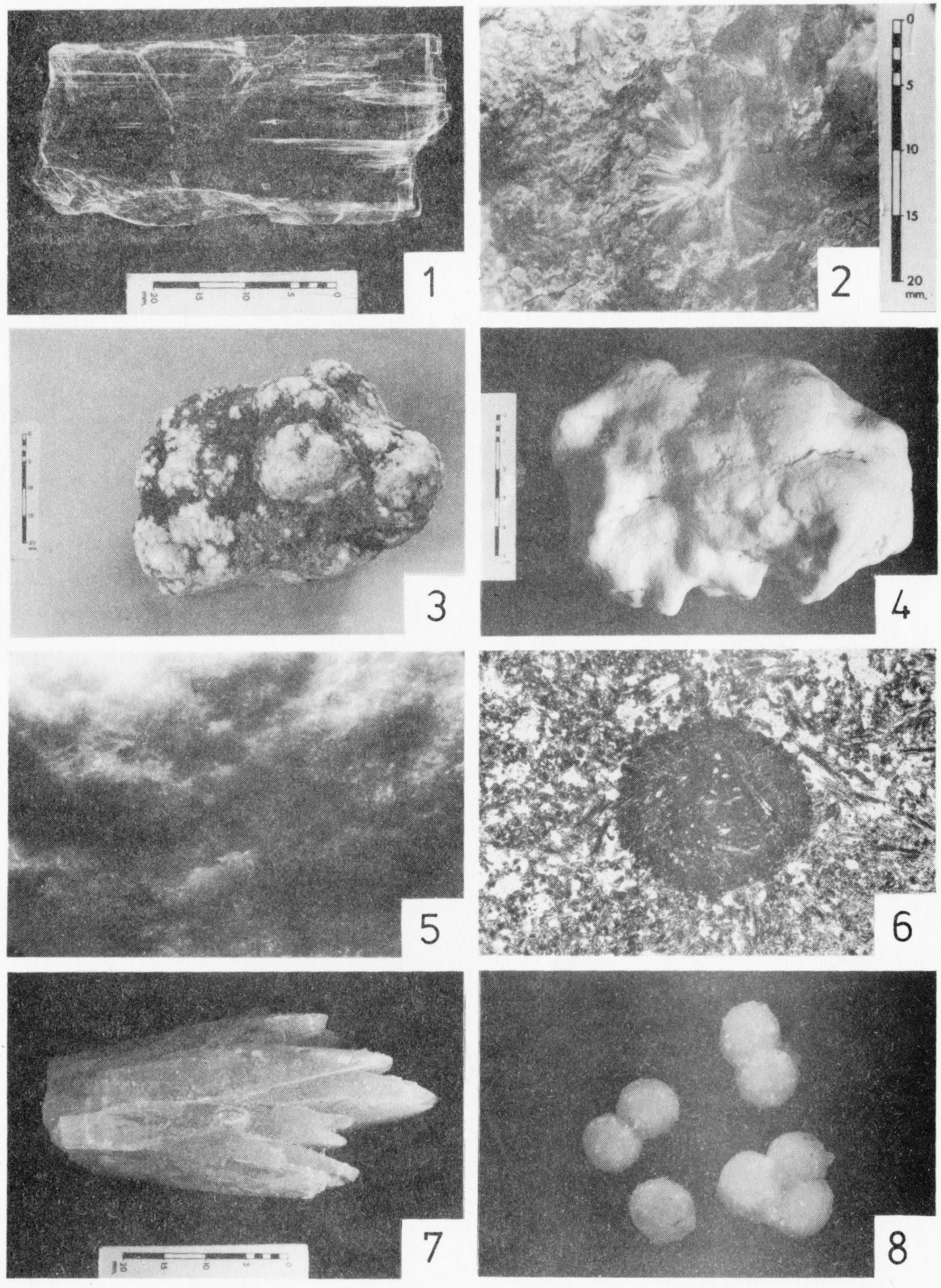

Helvaci - Turkish borates (explanation p. 270).