

# ANTIMONY

by

William Vickers Smitheringale

A Thesis submitted for the Degree of

MASTER OF APPLIED SCIENCE

in the Department of

GEOLOGY

The University of British Columbia

April 1925

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MAP.

## ANTIMONY.

### I. INTRODUCTION.

The present thesis was written at the University of British Columbia, in the Department of Geology, under the direction of Dean R. W. Brock. The writer is indebted to Dr. W. L. Uglow, Professor of Mineralogy, The University of British Columbia, for helpful suggestion and criticisms in regard to the subject matter in this report.

The first part of the thesis is a brief outline of the sources, properties and uses of antimony and the methods of extracting antimony from its ores. This is not complete in every detail, but is intended to give the reader a general conception of antimony in the commercial world. A brief summary of the economics of antimony is included. While this deals only with the outstanding points, it may be of some use in comparing antimony with other metals on the commercial market.

The latter part treats with the 'Geology of Antimony'. The information contained in this thesis, is of necessity derived from the reports of others. In summarizing and arranging this subject matter the writer has attempted to bring out the important facts contained in the reports and has give only sufficient detail to illustrate the various points. The reader is referred to the bibliography if he should require further details of any of the reports contained herein.

## II. SUMMARY AND CONCLUSIONS.

Prior to the war Great Britain was the chief smelter of antimony ores, but since then the Chinese and Japanese have obtained control of the American market. China is the largest antimony producer, capable of supplying the world demand, while America and Great Britain are the chief consumers.

Stibnite is the principal ore of antimony although its oxidation products, cervantite, kermesite, valentinite, stibiconite and native antimony may also be of importance. These oxides may also be derived from other antimony minerals as jamesonite.

Workable antimony ores occur in Mexico, California, Nevada, Canada, Alaska, Japan, China, Borneo, Australia, New Zealand, South Africa, Asia Minor, Algiers, Italy, Sardinia, Corsica, France, Spain and Portugal.

Stibnite and other antimony minerals may occur in association with gold, silver, lead, etc., and in such cases the associated metal may be of more importance and the deposit worked for such rather than for the antimony.

Antimony minerals are deposited from rising thermal alkaline solutions, originating in an igneous magma. They have a wide range of temperature distribution, being found in contact metamorphic deposits and in those now forming at the surface from hot spring waters. The deposits of economic importance for their antimony content are believed to have been formed principally at intermediate temperatures.

Antimony minerals are genetically associated with

igneous rocks of the granite, monzonite or diorite groups and are, perhaps, somewhat more abundant with the more acidic types.

### III. HISTORICAL SKETCH.

Stibnite has been known since very early times, especially in the Eastern countries, where women have used it for many centuries to darken their eyebrows and eyelashes and to add lustre to the eyes. Reference is made to it in the Old Testament, and the Arabs called it "Kohl". The Greek Dioscorides refers to it as "*στίβνις*"; Pliny as "Stibium"; Geber as "Antimonium" and the German writes it as "Speiseglanz". The derivation of the word antimony is not known.

Antimony, as an element, was first isolated in 1460 A.D., by Basil Valentine. In 1556 A.D., Agricola<sup>(1)</sup> describes several methods of assaying for antimony, and for the recovery of the metal from its ores.

Following its isolation in 1460 A.D., antimony was extensively used as a medicinal agent, but as such it became so badly abused that in 1566 the Parisian Government prohibited its use in medicines. Agricola mentions its use in alloys such as type metal. Since Agricola's time the demand for antimony has increased in proportion as new properties and uses of the metal have been discovered.

From 1897 - 1911 the average world production of antimony metal per year, from its ores, was slightly in excess of 10,000 metric tons with an average price of 7.5¢ per pound.

- - - - -

(1) De Re Metallica.

From 1911 - 1914 the production increased from 15,000 to 22,000 metric tons per year with the price remaining at 7.5¢ per pound. During the war the production increased tremendously, reaching a maximum of 82,000 metric tons in 1916. From then until 1920 the output gradually decreased to 20,000 metric tons per year. Since then the antimony ores have supplied, on an average, about 17,000 metric tons yearly.

The price of antimony since 1914 to the present has been very erratic. It reached its maximum of 32¢ per pound in 1915 and then declined to 8¢ per pound in 1919. Since then the monthly price has been very unstable, fluctuating a great deal between 5¢ to 19¢ per pound.

The above data do not include the amount of antimony which is recovered from hard lead and scrap, which amounts to 5,600 metric tons annually in the U.S.A.

#### IV. SOURCES OF ANTIMONY.

Besides being extracted from its ores, antimony is derived, to a considerable extent, from antimonial lead, a byproduct from smelting silver-lead ores containing some antimony. It is also recovered from scrap dross and other waste materials, and to a slight extent from some copper ores.

(1)

#### V. CHARACTERISTIC PROPERTIES OF ANTIMONY.

1. Antimony is a silver white, crystalline, brittle metal with a white lustre. Its specific gravity is 6.7 - 6.86, hardness 3 - 3.5 and it melts at 432° C and boils between 1090° and 1600° C.

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(1) Dictionary Applied Chem. Thorpe. Vol.1, p.280.

5.

2. It expands on solidifying from a melt.

3. Antimony combines readily with metals such as tin, copper, zinc and lead, and imparts to its alloys,

(a) hardness

(b) makes them more resistant to acid and alkaline solutions. This is important in chemical works, pump manufacture and water pipes.

(c) The property of expanding on solidification from a melt. This is important in castings and type manufacture.

4. Quite stable in air at ordinary temperatures, but when heated in air or oxygen to a red heat, it burns to the trioxide  $\text{Sb}_2\text{O}_3$  with the production of dense white fumes.

5. Burns in chlorine, especially if powdered.

6. Decomposes steam at red heat.

7. Dissolves in all warm, concentrated strong acids as nitric, sulphuric and hydrochloric; dilute hydrochloric and sulphuric acids do not affect antimony but nitric acid reacts with it under all conditions forming the various oxides; hydrochloric and sulphuric acids form the chloride and sulphate respectively. It is soluble in alkaline solutions.

8. Coef. of expansion  $.64 \times 10^{-5}$  per degree F.

9. Tensile strength of cast antimony about 1,000 lbs. per sq. in.

10. Comparatively a poor conductor of heat and electricity.

11. Diamagnetic.

12. Marked thermo electric properties and used in manufacture of thermopiles.

13. Poisonous. Acts very similar to arsenic in this respect.

14. Included in the same family as phosphorus, nitrogen, arsenic and bismuth.

#### VI. USES OF ANTIMONY.

(1)  
"The peace time uses of antimony are many, but only a few require large quantities of the metal. ... Its field of uses, however, exclusive of abnormal war demand, is widening and the consumption is increasing."

The unalloyed metallic metal has a few industrial uses, such as in the manufacture of pigments, and in producing a metallic finish on pottery. The chief use of antimony, however, is in alloy with other metals.

(2)  
"The antimony oxides are used chiefly for making white enamel and glass. the oxides and sulphides as coloring agents and pigments, and the sulphides in vulcanizing rubber. The oxide is used also in proportions up to 1½% in the manufacture of litharge... It is used in making colloidal products employed in medicine and surgery, in tanning, in the preparation of cosmetics, for the protection of plants and for the impregnation of wood fabrics."

(1) Mineral Resources, U.S.G.S., part 1, p.284, 1923.

(2) Mineral Resources, U.S.G.S., part 1, p.284, 1923.

## 1. Alloys of Antimony.

Antimony alloys with most of the heavy and the alkaline metals. It generally increases the hardness, brittleness and fusibility of the metals with which it alloys and imparts to them the valuable property of expanding on solidification. The alloys of gold, silver and lead have a greater density than their mean constituents, while those of iron, tin and zinc are of less density than their mean constituents.

(1)

## Alloys with Lead.

(a) Type metal. This is essentially an alloy of lead and antimony with sometimes minor amounts of tin, bismuth or copper.

(b) Hard Lead composed of varying amounts of lead and antimony is used in manufacture of lead pumps, pipes and valves where they must resist acid and alkaline solutions.

(c) Antimonial Lead. Is used a great deal in storage batteries.

## Alloys with Tin.

(a) Britannia metal. Essentially tin and antimony with minor amount of copper. Increasing the antimony increases the hardness, raises the melting point and reduces the malleability of the alloy. It is used in castings, domestic utensils and as a base

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(1) Dictionary of Applied Chem. Thorpe Vol.1.



8.

for electroplating; it is harder than pewter and is replacing that alloy.

(b) Bearing or Antifriction Metal. The better grades contain antimony, tin and copper in varying proportions. These alloys are soft, malleable, and are capable of standing relatively high temperatures without fusing.

#### Alloys with Copper.

Frequently added to copper and brass to intensify their color. These compounds are harder, finer in texture and take a better polish than brass or copper, and for this reason are often used in copper mirrors and reflectors.

#### Alloys with Zinc.

Forms crystalline compounds differing widely in composition but retaining the same form. They decompose water rapidly at boiling temperature and give a possible source of pure hydrogen.

#### Alloys with Aluminium.

These alloys expand on solidifying, are hard and fairly malleable and are unaltered by air or water at ordinary temperatures; they are also light.

#### 2. Artificial Chemical Compounds.<sup>(1)</sup>

Antimony unites directly with the halogen group

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(1) Dictionary of Applied Chem. Thorpe Vol.1.

with the evolution of heat and light; with hydrogen giving  $\text{SbH}_3$  (stibine) a colorless, poisonous gas with an offensive smell; and also with arsenic and phosphorus.

Antimony Trisulphide  $\text{Sb}_2\text{S}_3$ .

Used to some extent in the refining of gold from silver and copper. It is also used in the preparation of safety matches, percussion-caps, pyrotechny and veterinary surgery.

Antimony Pentasulphide  $\text{Sb}_2\text{S}_5$ .

Used in the vulcanizing of rubber, and as a yellow color in art paintings, glass and ceramic industries.

Antimony Trichloride  $\text{SbCl}_3$ .

Used as a caustic in medicines; in the manufacture of Tartar Emetic, and in bronzing gun barrels.

Antimonious Oxide  $\text{Sb}_2\text{O}_3$ .

Used for pharmaceutical purposes; preparation of Tartar emetic and as a substitute for white lead.

Tartar Emetic; A Potassium Antimonium Tartarate

Used in medicines and pomades and as a mordant in dying.

3. Uses of Antimony in their Relative Importance. <sup>(1)</sup>

1. Babbit metal.
2. Hard lead including pipes, etc.

- - - - -

(1) Eng. & Min. Journ. Press Sept. 27/24.

10.

3. Soft metal alloys and solder.
4. Type and Type metal.
5. Vulcanizing rubber and rubber goods.
6. Shrapnel and other bullets.
7. Special bearing and Antifriction metals.
8. Battery Plates.
9. Enamel on Metal ware.
10. Cable coverings.
11. Chemicals, paints and pigments.
12. Brass including bronze.
13. Britannia metal.
14. Collapsible Tubes.
15. Foil.
16. Used in Pyrotechnics as a filler.
17. Used in manufacture of thermopiles.
18. Used as a poison and in this respect acts very much like arsenic.

The above is for the war years of 1917 and 1918. If a census of today were made there would be a decrease in the demand for shrapnel and other bullets, and an increase in its use for hard lead, battery plates, rubber industry, cable coverings, etc.

(1)  
4. Substitutes.

"There are a number of other metals or materials which will harden lead and therefore can be used as substitutes

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(1) Mineral Resources, Part 1, p.286. 1923.

for antimony in lead alloys, but antimony is cheaper than most of the substitutes, and as the antimony deposits of the world are abundant in proportion to the consumption of the ore, the course of industry seems more likely to develop new uses for antimony."

"Of the ten or more known substitutes for antimony, the best found in recent years is a combination of calcium and barium..... The process is electrolytic, and calcium-barium-lead alloys are now made on an extensive scale." Other substitutes for antimony are barium and bismuth; for the antimony oxides, tin oxide and other white oxides may be used in paints and pigments; pure lead sulphide and iron sulphide may be used as substitutes for antimony sulphide in primers of shells and cartridges.

## VII. METALLURGY OF ANTIMONY.

### 1. Mechanical Concentration.

The ore of antimony, usually stibnite, may be either reduced directly or first subjected to mechanical concentration. The concentration <sup>(1)</sup> of stibnite is very difficult because stibnite is extremely friable and slimes very badly. It is impossible to save these slimes by any known gravitational process. The best recovery of antimony is obtained by employing a floatation process.

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(1) Lake George Antimony Ores and their concentration. C.S. Parsons. C.M.Journ. Vol.45, October 3/24, p.984.

## 2. Smelting.

In the direct method, metallic antimony and its compounds are nearly always extracted from the ores by dry methods.<sup>(1)</sup> According to their suitability for the several methods of treatment, the ores fall into two classes; sulphide ores containing more than 40% stibnite; and sulphide ores containing less than 40% stibnite and oxide ores of all grades. This latter class includes liquation residues and flue deposits.

## (a) Ores Containing more than 40% Stibnite.

If the ores contain more than 90% of the sulphide, no preliminary treatment is necessary, but if their content is lower than this they are first put through a process of "liquation" in which the sulphide is melted and allowed to run away from the gangue. The temperature of liquation must be carefully regulated, as too high a temperature causes excessive loss by volatilization, and too low a temperature results in a low recovery of the sulphide.

In the English method the ore is ground to the size of hazel nuts or smaller and then subjected to two processes before refining. The first process is carried on in crucibles in reverberatory furnaces. Each crucible holds 42# ore, 16# iron scrap, 4# salt and 1# slag from "doubling". This charge is kept in a state of fusion for two or three hours, at the end of which time the antimony is removed from beneath

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(1) Dictionary of Applied Chem. Thorpe Vol. 1.

the slag and poured into moulds. This product is known as "singles" and contains about 91% Sb.

The second process is carried on in similar crucibles and furnaces as above. The charge to each crucible is 84# broken singles, 7-8# liquated sulphide and 4# salt. The whole is kept in a state of fusion for 1½ hours; the completion of the operation being determined by the nature of the slag. The slag is removed by ladles and the product is run into moulds and later refined. This product is known as "bowl metal", or "star bowls".

The losses in the English process, by volatilization are small, ranging from 2% to 5%.

(b) Ores Containing less than 40% Stibnite.

The ores of this type are roasted either to the non volatile tetroxide or the volatile trioxide, or are subjected to one of the direct reduction processes. A process that is becoming quite popular and which has marked advantage is the "Volatilization Process", in which there is continuous roasting of the ore to the trioxide ( $\text{Sb}_2\text{O}_3$ ).

The oxidation to the trioxide takes place at about 400° C with the carefully regulated amount of air. Any one of the modern fume condensing systems may be employed to condense the fumes, according as it is thought to be best suited to the purpose.

With suitable condensing apparatus this process has marked advantages, especially with poor ores. It may be noted that any arsenic is separated as the more volatile tri-

oxide and any gold or silver is left in the residue and may be extracted later. There is no loss of antimony and the fuel consumption is low.

For the volatilization process the ideal ore is from 15% to 25% Sb.<sup>(1)</sup> Ores above 40% antimony are liquated as well as volatilized. The liquated sulphide forms an oxysulphide with the trioxide, which is known as antimony glass, which causes fritting in the lower part of the furnace. If ores of over 30% Sb are used, then 30% - 50% excess coke is required to volatilize all the stibnite.

(2)  
(c) Refining.

The unrefined antimony contains sulphur, iron, arsenic and sometimes copper and lead; the sulphur and iron being most plentiful, 2-10% and 0-5% respectively. The other impurities seldom exceed 1.5% combined.

All these impurities, except lead, may be removed by slagging with oxidizing, sulphurizing and chlorinating agents. Glauber salt and charcoal remove copper and iron as sulphides and arsenic as sodium arsenite. Antimony oxysulphide eliminates the sulphur. Chlorides as salt and carnallite must be used with caution as great loss by volatilization may occur.

Pure antimony, on solidifying has a beautiful fern leaf or "star" on the surface. The quality of the ingot may be determined by the length and form of this star, as rela-

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(1) C.Y. Wang. Trans. Am. Inst. of Min. Met. Eng. Vol. 60 p. 3.

(2) Dictionary of applied Chem. Thorpe Vol. 1. p. 276.

tively small proportions of impurities will prevent the metal from starrng. Through this peculiarity, the trade term "star antimony" has arisen for good quality of antimony.

### 3. Electrolytic Recovery.

Electrolytic recovery from a solution of the sulphide in sodium sulphide as an electrolyte has been proposed by the Germans, but the process has not appeared on a commercial scale.

(1)  
Mr. W. A. Burr claims that by crushing antimony ore to 8 mesh, and then leaching with a solution containing 7% sodium hydroxide and 2% sodium chloride, an economical recovery is obtained. The antimony is precipitated from this solution on steel electrodes by using a current density of 8-9 amp. per sq.ft. at  $2\frac{1}{4}$  -  $2\frac{1}{2}$  volts. The precipitate assayed 99.94% Sb.

### VIII. MARKETING OF ANTIMONY.

(2)  
"Practically all of the refined metal known in the trade as regulus, consumed in the United States is imported from China through the Port of New York. The importer sells the metal either direct to consuming interests or to dealers. The usually minimum import lot is 25 gross tons."

"The principal market is naturally in New York, and the out of town buyers purchase either through their New York offices or sales agent, or employ the services of brokers, to

(1) Eng. & Min. Journ. Vol. 104, 1917, p.789.

(2) H.K.Masters. Eng. & Min. Journ. Sept.27,1924.



whom the seller then allows a brokerage of  $\frac{3}{4}$  of 1% -----.

The principal industries using antimony products as raw materials are.....in Northwestern U. S. Very little is used west of the Mississippi....although there is a small consumption on the Pacific Coast...with distributing centres at San Francisco and Seattle. ... The demand for antimony is not a seasonal one, although...the market is usually more active in winter and early spring, and again in the fall...."

The world's average peace time consumption is estimated at 22,000 metric tons from ore produced, of which the United States uses 10,000. Besides this, the United States consumes 2,100 tons of antimony contained in the antimonial lead ores of domestic smelting, and 3,500 tons of antimony recovered from alloys, scrap, dross and waste materials.

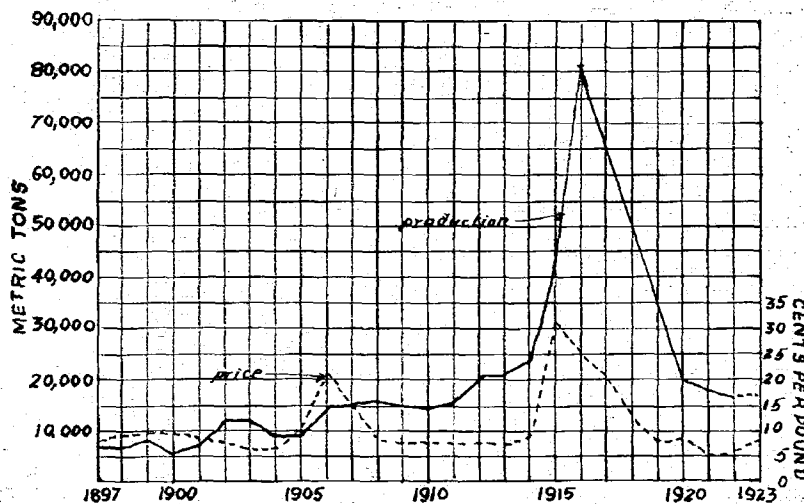
The specifications for the regulus are not critical, being, "that it shall contain a minimum of 99% Sb, as little arsenic as possible, and be uniform in quality. When the metal is imported no samples are taken. It is sold simply as prime Sb 99% pure, and invariably contains the guaranteed percentage." If pure antimony is needed for specific purposes, the buyer must analyze his shipment and then remove the harmful ingredients himself.

"The average price of antimony metal in New York for the last thirty years, ending 1914 was 7.50¢ per lb. for Cocksion's brand, (English). Since that year the Chinese metal has dominated the United States market, and the average price

for the ordinary metal, 99% pure, has been:-

| cents per lb. |       | cents per lb. |       |
|---------------|-------|---------------|-------|
| 1915          | 30.28 | 1920          | 8.48  |
| 1916          | 25.37 | 1921          | 4.96  |
| 1917          | 20.69 | 1922          | 5.47  |
| 1918          | 12.58 | 1923          | 7.90  |
| 1919          | 8.19  | 1924          | 12.70 |

The accompanying graph shows the production of antimony from its ores, from 1897 - 1923, and the corresponding price of antimony per lb., New York.



World production of antimony, 1897-1923. based on estimated recoverable content of antimony ore, and average price per lb. in New York.  
Mineral Resources. 1923. part I. p 292.

The above figures and graph show the effect of the war time demand on the metal antimony. The greatly inflated price stimulated production the world over, and as the supply gradually met the demand there was a corresponding drop in

price. The sudden drops in 1918, 1919 and 1921 were caused by the cessation of hostilities which resulted in a loss of a buying market. A further slump in price was caused by several of the belligerent countries dumping their excess shrapnel supplies on the market for their antimonial content. The gradual rise in price since 1921 indicates a corresponding depletion of scrap supply, and a growing peace time demand for the metal. During 1924 the price fluctuated a great deal, varying from 8.25¢ per lb. to 19.50¢ per lb.

In considering the price of antimony two things should be kept in mind.

(a) China is the chief producer of antimony.

(b) China has a silver standard currency.

As the Chinese producer is paid in silver, then the price of Antimony will vary with the gold value of silver. Other things being equal, a rise in the value of silver will be accompanied by a corresponding rise in the price of antimony and visa versa.

The principal foreign market for antimony ore is Great Britain which draws its supply principally from China, Mexico and Bolivia. The standard ore is stibnite, the price of which varies with the percentage of contained antimony, and the harmful impurities present. If the ore is of good quality, percentages as low as 50% Sb are saleable. The sulphide is preferable, but oxides are also bought at a slight discount. There is no fixed ratio between the price of antimony as ore and that of market regulus, the final price usually being a

mutual agreement between the buyer and seller. The usual parcel offer is at least fifty tons.

## IX. GEOLOGY OF ANTIMONY.

### 1. Natural Compounds.

In nature, antimony is found both in the native state and in combination with oxygen, sulphur, arsenic, lead, copper, silver and other elements. There is a considerable variety and number of these compounds. The following list contains the more common and important natural compounds of antimony:

|                           |   |
|---------------------------|---|
| Native Antimony . . . . . | Sb  |
| Stibiconite . . . . .     | 2 Sb O <sub>2</sub> . H <sub>2</sub> O                            |
| Cervantite . . . . .      | Sb <sub>2</sub> O <sub>4</sub>                                    |
| Senarmontite . . . . .    | Sb <sub>2</sub> O <sub>3</sub>                                    |
| Valentinite . . . . .     | Sb <sub>2</sub> O <sub>3</sub>                                    |
| Bindheimite . . . . .     | Pb <sub>3</sub> Sb <sub>2</sub> O <sub>5</sub> . aq               |
| Kermesite . . . . .       | 2 Sb <sub>2</sub> S <sub>3</sub> . Sb <sub>2</sub> O <sub>3</sub> |
| Stibiotantalate . . . . . | (SbO) <sub>2</sub> (Ta Nb) <sub>2</sub> O <sub>6</sub>            |
| Antimonates . . . . .     |   |
| Stibnite . . . . .        | Sb <sub>2</sub> S <sub>3</sub>                                    |
| Metastibnite . . . . .    | Sb <sub>2</sub> S <sub>3</sub>                                    |
| Tetrahedrite . . . . .    | Cu <sub>7</sub> Sb <sub>2</sub> S <sub>7</sub>                    |
| Pyrargyrite . . . . .     | Ag <sub>3</sub> Sb S <sub>3</sub>                                 |
| Stephanite . . . . .      | Ag <sub>5</sub> Sb S <sub>4</sub>                                 |
| Polybasite . . . . .      | Ag <sub>7</sub> Sb S <sub>6</sub>                                 |
| Dyscrasite . . . . .      | Ag <sub>3</sub> Sb  |

|                        |  |
|------------------------|--|
| Bournonite . . . . .   | Pb Cu Sb S <sub>3</sub>                        |
| Jamesonite . . . . .   | Pb <sub>2</sub> Sb <sub>2</sub> S <sub>5</sub> |
| Famatinite . . . . .   | Cu <sub>2</sub> Sb <sub>2</sub> S <sub>4</sub> |
| Boulangerite . . . . . |  |
| Wolfsbergite . . . . . |  |
| Allemontite . . . . .  | Sb As <sub>3</sub>                             |

## 2. Ores of Antimony.

### (a) Those used for Recovery of Antimony.

The most important ore of antimony is stibnite ( $\text{Sb}_2\text{S}_3$ , 71.4% Sb). Stibnite crystallizes in the orthorhombic system and is commonly found in radiating groups of prismatic, acicular or bladed crystals vertically striated. These crystals sometimes exhibit a step like appearance on the face  $b(010)$  due to shearing of the crystal. Massive and granular forms are also common. Stibnite has cleavage parallel to  $b(010)$  lustre metallic - highly resplendent on fresh cleavage or crystal faces. These soon take on a lead grey color, and in time tarnish to a blackish tone; sometimes to iridescence. Streak, lead grey; hardness 2; specific gravity 4.52-4.62, slightly sectile, subconchoidal fracture. Fuses easily in candle flame.

Metastibnite is an orange red, amorphous form of  $\text{Sb}_2\text{S}_3$ , which is formed in calcareous sinters derived from thermal springs as at Yellowstone National Park.

The oxides cervantite, senarmontite, valentenite, kermesite and stibiconite, if occurring in sufficient economic

quantities, are mined by themselves. They often occur in association with stibnite and in such cases are mined along with the sulphide ore.

Native antimony occurs in several places, as in New Brunswick; Kern County, Calif.; Sala, Sweden; Allemont and Dauphine, France; Sarawak, Borneo. It is believed that in all cases, native antimony is an oxidation product. It occurs finely or coarsely granular, compact, or in lamellar plates; associated with the oxides as valentinite, kermesite, etc., and the original stibnite; sometimes found in association with silver ores. Distinctive crystals are rarely met with; these are rhombohedral; perfect basal cleavage; sometimes twinned on rhombohedral plane  $c(110)$ ; Hardness 3-3.5; specific gravity 6.65-6.72.

These oxidized minerals may be derived from either the oxidation of stibnite, or from the alteration of such minerals as jamesonite or other sulphur antimony minerals.

Objectionable impurities in ores, used for the recovery of antimony are lead, copper, arsenic, zinc and bismuth. These impurities are penalized as follows:-

Lead up to 0.3% free; over 0.3 to 1.5% 5¢ per 0.1%. Some buyers stipulate that lead should not exceed 0.3%.

Arsenic up to 0.1% free; over 0.1% to 0.5% \$1.80 per 0.1% or part.

Copper carries the same penalties as arsenic; some buyers stipulate that there shall be no copper in the ore. Zinc and bismuth are very objectionable impurities in the ore

and should not be present in more than a trace. If present in an amount up to 0.5% they are subject to heavy penalties.

(b) Those Mined for Valuable Associate Minerals.

Gold is often found in association with stibnite. In such instances it may be more economical to mine and smelt the ore for the recovery of the associate mineral rather than for the antimony content. Examples of such are found in Alaska, Yukon Territory, Nova Scotia, Nevada, Mexico, New Zealand and elsewhere. Stibnite is often in association with cinnabar and such deposits may be worked solely for the mercury and not for the Sb.

Besides the association of valuable minerals with stibnite, such antimony compounds as pyrargyrite, stephanite, polybasite, jamesonite, tetrahedrite, etc., are mined primarily for their silver, lead or copper content rather than for the antimony value. These may occur in association with minor amounts of stibnite and are also found in association with argentiferous galena.

3. Associated Minerals.

Stibnite is found in association with other primary and secondary antimony minerals. The primary antimony minerals are associated with pyrite, galena, sphalerite, chalcopyrite, bismuthenite, arsenopyrite, pyrrhotite, scheelite, molybdenite, tin, cobaltite, gold, silver, cinnabar, realgar, orpiment, etc. The common gangue mineral is quartz which usually predominates and may occur massive, with stibnite disseminated through it, or else it may occur as idiomorphic

crystals in a segregated mass of stibnite. Calcite, barite, gypsum, siderite, tourmaline, contact silicate minerals and fluorite may also be present in minor amounts or may constitute the main gangue mineral with quartz entirely absent or in minor amounts.

#### 4. Oxidation of Antimony Ores.

Stibnite decomposes and forms the oxidation products, valentinite, senarmonite, cervantite, kermesite, stibiconite and native antimony. These may at times entirely replace the original stibnite, as in Algeria, Mexico, and Borneo. These same oxides may be obtained by the weathering of other antimony sulphide minerals as jamesonite, tetrahedrite, bournonite, etc. If lead is present during the process of oxidation, the aqueous lead-antimony oxide "bindheimite" may be formed.

While the oxides of antimony are common, its transportation by supergene underground waters is limited. It is, however, slightly soluble in these underground solutions, as is shown by the removal of antimony compounds from the gossan capping of deposits, which lower down contain antimony minerals. Traces of antimony are found in mine waters which have percolated through antimony compounds. Lindgren mentions secondary stibnite in the National District, Nevada.<sup>(1)</sup> He also states that stibnite is being deposited from the hot spring

(1) U.S.G.S. 601, 1915.



waters (80° C) in Yellowstone National Park. <sup>(1)</sup> "W. H. Malcolm <sup>(2)</sup> claims that stibnite is being deposited at the present time in the West Gore Mine, Nova Scotia, and also a "red sulphide" perhaps kermesite ( $\text{Sb}_2\text{S}_2\text{O}$ ) is said to be forming, both probably from alkaline waters." <sup>(3)</sup> C. Dolter and others have shown experimentally that stibnite is soluble in pure water at 80° C and will recrystallise again as stibnite from the same solutions. This is important in the natural process, but it is not final. These experiments also showed that while stibnite reacts only very slowly in neutral and acid solutions it is one of the most active minerals in alkaline solutions; its activity being exceeded only by that of orpiment when solutions of alkaline carbonates or hydroxides were used. Such solutions would be capable of transporting the dissolved antimony long distances from its original source. It is probable that where antimony compounds have been dissolved and transported, the process has been carried out through the agencies of alkaline solutions.

Antimony forms the sulphate  $\text{Sb}_2(\text{SO}_4)_3$ . Stibnite is very slowly attacked by sulphuric acid, even in the presence of ferric sulphate, with the formation of the sulphate  $\text{Sb}_2(\text{SO}_4)_3$ , which, however, is unstable in water and is unknown in ore deposits. <sup>(4)</sup> "This tendency of the antimony sulphate to hydrolyze and form insoluble oxides prevents its extensive migration

(1) Tr. Am. Inst. Min. Eng. Vol. 36, 1906.

(2) Lindgren, "Mineral Deposits", 1919, p. 900.

(3) Clarke, U.S.G.S. 695, p. 633. W.H. Emmons, U.S.G.S. 625-1917.

(4) W.H. Emmons, U.S.G.S. 625, 1917, p. 409.

in weakly acid or neutral sulphate solutions. Hydrochloric acid readily dissolves the sulphide but an oxidizing agent, like ferric salt, will precipitate antimony oxide. There is no soluble carbonate. Thus the chemical relations, as well as geological occurrences, indicate that the metal is not highly mobile in the acid solutions of superficial weathering zones." According to Shurmann's series antimony sulphide would be expected to replace various other sulphides but no examples of this have so far been found.

It was previously stated that stibnite was readily soluble in solutions of alkaline carbonates or hydroxides. "With these solutions <sup>(1)</sup> it forms double salts like  $\text{Na}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ , which readily precipitate silver and copper from their solutions. Thus probably are formed the sulphantimonates, pyrargyrite and stephanite and other secondary minerals." "In the following table <sup>(2)</sup> the more important antimony sulphosalts of silver are put in the first column and the arsenic sulphosalts in the second. Tetrahedrite and tennantite are included for they are commonly argentiferous.

|              |  |            |  |
|--------------|--|------------|--|
| Pyrargyrite  | $3\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ | Proustite  | $3\text{Ag}_2\text{S} \cdot \text{As}_2\text{S}_3$ |
| Tetrahedrite | $4\text{Cu}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ | Tennantite | $4\text{Cu}_2\text{S} \cdot \text{As}_2\text{S}_3$ |
| Stephanite   | $5\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ |            |  |
| Polybasite   | $9\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ | Pearceite  | $9\text{Ag}_2\text{S} \cdot \text{As}_2\text{S}_3$ |

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(1) W.H.Emmons, U.S.G.S. 625, 1917 p.409.

(2) W.H.Emmons, U.S.G.S. Bull. 625, 1917, p.262.

"The minerals of the first column are, as a rule, much more abundant and they are of more common occurrence than the corresponding minerals of the second column. .... If the antimony sulphosalts, where secondary, have been deposited mainly as ~~the~~ results of reactions of silver-bearing sulphate waters on stibnite, it would appear that arsenic minerals are less common than antimony minerals or else that they are less rapidly replaced under the conditions that exist in veins. But arsenic is as abundant in ore deposits as antimony and is much more readily dissolved in acid solutions. These relations and many others suggest that the complex antimony and arsenic sulphosalts of silver are formed in an alkaline environment. In such an environment antimony and arsenic sulphides are very readily dissolved. L. G. Raviez <sup>(1)</sup> has shown that pyrargyrite is about 1/10 as soluble in alkaline solutions as proustite and therefore could be more readily precipitated from diluted solutions." These complex silver antimony sulphosalts are formed in and below the zone where argentite forms. H. C. Cooke <sup>(2)</sup> has shown that powdered stibnite (-80 mesh) when soaked in a silver sulphate solution, 1/30 N, for 36 days contained 1.3% of silver. The nature of the silver minerals was not stated.

<sup>(3)</sup>  
 "Dyscrasite is really an alloy of silver and antimony of varying composition; it has formed important ore at

(1) L.G. Raviez. Experiments in the enrichment of silver ores. Ec.Geol.Vol.10, 1913, p.378-384.

(2) H.C.Cook, Secondary enrichment of silver ores, Journ.Geol. Vol.21 1913, p.1-29.

(3) Lindgren, "Mineral Deposits." 1919. p.884.

Broken Hill and Chanarcillo and is also known from Cobalt.

### 5. Occurrence and Distribution of Antimony in the Various Countries.

Stibnite, the chief ore of antimony, is commonly distributed in mineral veins throughout the world, but only in relatively few localities is it of sufficient concentration to be considered as an ore of antimony. In many instances stibnite is associated with gold, silver, copper and lead, and in such cases the ore is treated for the recovery of these metals and not for its antimony content.

Besides occurring as the sulphide "stibnite" antimony is present in many compounds, such as pyrargyrite, jamesonite, tetrahedrite, stephanite, etc. These are also commonly found and are usually mined primarily for the valuable associated mineral and not for antimony.

(1)  
"The percentages of the world's production of antimony in 1913 by countries was:

|                            |      |                  |    |
|----------------------------|------|------------------|----|
| China .....                | 53%  | Algeria .....    | 1% |
| France .....               | 21%  | Asia Minor ..... | 1% |
| Mexico .....               | 10%  | Italy .....      | 1% |
| Austria Hungary ..         | 8%   | Serbia .....     | 1% |
| Australia (Victoria) ..... | 4.2% |                  |    |

Since 1914, 60% of the world's supply has come from China. "During 1922 ... China supplied 90% of all the ore

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(1) Mineral Resources. U.S.G.S. 1923. Part 1. p.292.

TABLE 1.

(Approximate recoverable metal content of ore produced, exclusive of antimonial lead ores.)

| Country                     | 1917  | 1918  | 1919  | 1920  | 1921  | 1922  | 1923    |
|-----------------------------|-------|-------|-------|-------|-------|-------|---------|
| <b>NORTH AMERICA:</b>       |       |       |       |       |       |       |         |
| Canada .....                | 87    | a7    | a14   | ..... | ..... | ..... | .....   |
| Mexico .....                | 2647  | 3279  | 471   | 623   | 45    | 464   | 490     |
| United States ..            | 310   | 45    | ..... | ..... | ..... | 4     | 8       |
| <b>SOUTH AMERICA:</b>       |       |       |       |       |       |       |         |
| Argentina b ....            | 650   | 360   | 27    | 50    | (c)   | (c)   | (c)     |
| Bolivia a .....             | 10288 | 3010  | 105   | 484   | 282   | 185   | 312     |
| Peru a .....                | 433   | 155   | 30    | 7     | 7     | ..... | .....   |
| <b>EUROPE:</b>              |       |       |       |       |       |       |         |
| Austria .....               | 38    | ..... | 1     | ..... | ..... | 139   | 62      |
| Czechoslovakia .            | (d)   | (c)   | 153   | 330   | 384   | 100   | (c)     |
| France .....                | 2354  | 1329  | 998   | 1130  | 1276  | 656   | 437     |
| Greece .....                | ..... | ..... | 55    | 46    | ..... | ..... | .....   |
| Hungary .....               | 406   | (c)   | 66    | 93    | ..... | ..... | (c)     |
| Italy .....                 | 689   | 404   | 10    | 187   | 76    | 146   | 271     |
| Spain .....                 | 148   | 22    | ..... | ..... | ..... | ..... | 25      |
| Yugoslavia .....            | 725   | (c)   | (c)   | (c)   | (c)   | (c)   | 131     |
| <b>ASIA:</b>                |       |       |       |       |       |       |         |
| China a .....               | 28450 | 15597 | 7721  | 13001 | 14658 | 13858 | e 14500 |
| India, British ..           | 61    | ..... | 2     | ..... | 1     | ..... | .....   |
| Indo-China .....            | a800  | (c)   | (c)   | (c)   | (c)   | ..... | .....   |
| Japan .....                 | 1606  | 95    | 1     | ..... | ..... | (c)   | (c)     |
| Turkey (Asia Minor)         | f400  | f400  | f400  | f400  | f400  | f400  | f400    |
| <b>AFRICA:</b>              |       |       |       |       |       |       |         |
| Algeria a .....             | 4550  | 2218  | 723   | 1000  | 103   | 579   | 500     |
| Nigeria a .....             | ..... | ..... | (g)   | (g)   | (g)   | (g)   | (c)     |
| Rhodesia, Southern Union of | 3     | 3     | ..... | 2     | ..... | ..... | .....   |
| South Africa ...            | 232   | 38    | 10    | ..... | ..... | ..... | .....   |
| <b>OCEANIA:</b>             |       |       |       |       |       |       |         |
| Australia-                  |       |       |       |       |       |       |         |
| New South Wales             | 150   | 143   | 70    | 81    | 50    | ..... | .....   |
| Victoria .....              | 1045  | 509   | 491   | 406   | 141   | 605   | 421     |

a. Exports.

b Railway shipments. A large part of the shipments reported are probably of Bolivian origin and there fore may duplicate in part the quantities shown for Bolivia.

c Data not available.

d Included under Austria and Hungary.

e Calculated from estimates in Mining Industry, vol.32,p.46,1923.

f Estimated.

g Less than 1 ton. The estimated recoverable metal content of ores exported was as follows: 1919,169 kilograms; 1920,178 kilograms; 1921,74 kilograms; 1922, 190 kilograms.

mined in the world and in 1923 China's output... was about 80% of the world's production".

"The world's present capacity for producing antimony far exceeds the normal demands. New deposits of antimony are being found from time to time".

Table I shows the world's production for the years 1917-1923 as far as reasonably approximate data are available.

(a) China:

Although the antimony deposits of China are the largest in the world there is comparatively very little detailed geological information available. The deposits occur in many places throughout central and southern China<sup>1</sup>, but 90% of the production comes from the province of Hunan in a zone extending from Yi-yang southerwest through An-hua, Hsin-hua and Pae-ching. Another zone, further south, extends from Chukiang in northern Kwantung through Kwangsi and Kwee-chow to Wenshan and Ani in eastern Yunnan.

The deposits of Hunan<sup>2</sup> occur in a Paleozoic series of quartzites, shales and limestones (mentioned in their stratigraphical sequence) overlain by Mesozoic strata. These rocks have been folded, resulting in the formation of anticlines, synclines, domes, sheared zones and faults.

1. China Year Book, 1923, P. 124, U.S.G.S. Atlas of Commercial Geol. 1921, Part 1, P. 63. C. D. Hubbard, Am. Journ. Sc. Series 5, Vol. 4.
2. Bull. Geol. Survey, China No 3, Oct. 1921, P. 1 - 26.

The ore occurs principally in the quartzite along the sheared and brecciated zones and in the domes along the axis of the antiforms. In these latter instances the overlying impervious shale has played an important part in trapping the solutions and thus forming important ore bodies.

The Ore is chiefly stibnite. This is usually well crystallized and is found in segregated masses of varying size. The brecciated zones are characterized by fine veinlets, veins and irregular lenses of almost pure stibnite; a small amount is also disseminated through the quartzite. There are few other minerals present; Cinnabar is found in association with the stibnite in some areas, and occasionally a small amount of pyrite is also present. The gangue is quartz which is generally massive but druses, lined with quartz crystals, are frequently found.

At the surface the stibnite has been oxidized; the oxides present are not definitely known but probably include cervantite, senarmontite and stibiconite. These are frequently found as pseudomorphs after stibnite but seldom have any well crystallized form of their own.

The geological age and genesis of these ores are not definitely known, but tentatively it is suggested that they are genetically associated with the intrusion of Tertiary granites.

At Shin Chow<sup>1</sup> in the province of Kwangtung stibnite occurs near the contact of steeply dipping Paleozoic shales and limestones. The ore is disseminated through the limestone, and probably represents a metasomatic replacement deposit. The only gangue present is calcite; small amounts of pyrite are sometimes disseminated in the limestone along side of the stibnite. Surface oxidation of the deposit has resulted in the formation of various antimony oxides.

Most of the antimony ores are treated in China, producing either crude antimony or regulus. Since very little antimony is used in China practically the whole output is exported, chiefly to Japan and America. In 1913 China supplied 53% of the world's production and at present is contributing over 60% of the total world output.

1. G. D. Hubbard. The Am. Mineralogist Vol.7  
# 8, Aug. 1922



(b) France.

The antimony production of France, amounting to about 21% of the world's total in 1913, is absorbed chiefly by home industries. Deposits of antimony occur in the departments of Mayenne, Cantal, Allier, Haute Loire, Haute Vienne, Bambonnais, Sauvigny, Alsace, Brittany and the Island of Corsica.

The deposits generally occur in fissure veins cutting granites, granite gneisses and schists, slates and graywackes and are genetically associated with granitic intrusives. The vein filling is composed chiefly of quartz, with some calcite and barite and stibnite which is either disseminated through the quartz or is found in segregated bodies of almost pure sulphide. These segregations vary in width from fractions of an inch to three feet or more and are irregular lens shaped bodies separated by zones of barren quartz or quartz through which varying amounts of stibnite are disseminated. Deposition probably occurred under intermediate and low temperature conditions. Native antimony occurs at Allemont and Dauphene.

The largest producer is Mayenne<sup>1</sup> northwestern France, where the stibnite is associated with auriferous quartz and pyrite. In the Central Plateau the antimony deposits of Freycenet occur in fissure veins cutting Archean gneisses and schists. There are several antimony bearing veins

1. U.S.G.S. World Atlas of Commercial Geology 1921.

some of which contain complex antimony, lead and argentiferous ores. "The antimony<sup>(1)</sup> ore is very pure sulphide slightly altered near the surface to white and yellow oxide. The veins are either filled with country rock or ... compact bluish quartz spangled with fine needles of stibnite when the vein is poor and disappearing almost entirely when the vein becomes richer." The associated minerals are small amounts of pyrite, pink and white calcite and traces of sphalerite. The stibnite is neither auriferous nor argentiferous.

In Montignat<sup>(2)</sup> Allier, stibnite veinlets of extreme irregularity are found in a granulite dyke cutting granite gneiss.

At Mercœur,<sup>(3)</sup> Haute Loire, the Bissade lode "may be followed for a length of 2500 m. ... with a width of 30-60 cm. of solid stibnite accompanied by a little quartz. In places the lode breaks up into several veins. The separation from the gneiss is fairly sharp, though veins and nests are occasionally found beyond the walls." At Valadon stibnite occurs in a fissure vein cutting old slates. The ore is found in irregular shoots, separated from each other by barren areas. No alteration of the wall rock has occurred. Erratic deposits occur at Malbosc, Ardeche. They are quartz stibnite lodes with some calcite and barite.

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(1) Abst., Trans.Fed.Inst.of Min.Eng. Vol.6,1893-94, p.579.

(2) Abst., Trans.Fed.Inst.of Min.Eng. Vol.24,1902,p.692.

(3) Truscott Ore Deposits Vol.2,1914 p. 782.

In the Island of Corsica <sup>(1)</sup> "the antimony

occurs as stibnite in veins cutting through hornblende and sericite schists ... The gangue is quartzose in character ... The vein is generally richest near the foot wall, which is always better marked ... than the hanging wall." The associated minerals are pyrite, sphalerite, bournonite, some cinnabar and calcite.

(c) Mexico.

Mexico produces 10% of the world's antimony and ships its product chiefly to the United States or to England. The deposits occur in the states of Sonora, San Luis Potosi and Queretaro. There are two types <sup>(2)</sup> of deposit which serve as an ore of antimony.

1. Quartz stibnite veins, with galena and zinc blende as associated minerals, occurring in hornblende and pyroxene andesites.

2. Veins occurring in limestones and slates, and containing cerussite, stibiconite and valentinite; these oxides changing to sulphides in depth. Such veins are very irregular.

The deposits of El Altar, Sonora, <sup>(3)</sup> are considered as oxidized metasomatic replacements in Carboniferous limestones. The deposit at present consists of almost

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(1) Abst. Trans. Fed. Inst. Min. Eng. Vol. 15, 1897, p. 540.

(2) Aquitera-Trans. Am. Inst. Min. Eng. Vol. 32, 1902, p. 507.

(3) D. D. Cairnes, Journ. C. M. Inst. 1910, p. 308; E. T. Cox, Tr. Am. Journ. Sc. 1880, Vol. 20, p. 421; E. Halse, Trans. Fed. Inst. Min. Eng. Vol. 6, 1894, p. 290-294.

pure stibiconite between irregular walls of limestone. The impurities are cerargyrite and quartz, the latter increasing with depth as the stibiconite decreases.

Stibnite commonly occurs with galena and is frequently found in association with cinnabar in irregular fractures and replacements in limestone. Instances of the latter are found in San Luis Potosi where stibnite occurs in association with livingstonite, kermesite, barcosite and a small amount of cinnabar in a matrix of gypsum. Stibnite is not infrequently found in silver veins and accompanies argentiferous tetrahedrite. At Triunfo and San Antonio, stibnite is in association with jamesonite, berthierite, galena, pyrite, sphalerite and tetrahedrite, which have become oxidized near the surface to antimony oxide and bindheimite. The same association occurs in Sonora. At Zimapan,<sup>(1)</sup> jamesonite occurs in a typical contact metamorphic deposit in limestone.

(2)

"The tin occurrences in Mexico differ from the usual type in so far as they are not found in connection with granite but with rhyolite .... The mineral association is, however, the same as with normal granite. The deposits occur more particularly ... in Durango and ... in Jalisco ... along joint planes and fault fissures in rhyolite and rhyolite tuff. They carry kaolin, quartz, chalcedony, opal and feldspar together with specularite, fluorite, topaz, durangite and more rarely

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(1) Lindgren and Whitehead Ec. Geol. Vol. 9. 1914. p. 435.

(2) Truscott, Ore deposits, Vol. 1. 1914. p. 447.

wolframite and bismuth ore. ... It is worthy to remark that the tin won from these deposits contains a striking amount of antimony."

The antimony deposits of Mexico occur either as fissure veins or as replacements in limestones and are genetically associated with igneous rocks of andesitic or more acid character. Their mode of deposition ranges from contact metamorphic to low temperature near surface conditions.

(d) Austria-Hungary and Bohemia.

During 1913 Austria-Hungary produced 8% of the world's antimony ores. The deposits occur in northern Hungary and in the Rechnitz mountains. In the former locality there are large reserves of auriferous stibnite ore of fairly low grade, but the production is steady. In the Rechnitz mountains "The veins ... cut crystalline schists ... and are especially rich when the country rock is a chloritic or graphitic schist. The vein filling consists of quartz, calcite and stibnite, with stibiconite and pyrite .... The graphitic schists along side the lode, for a distance of 3 to 4 metres from the vein walls, are richly impregnated with stibnite, together with pyrite and cinnabar....."

Other veins of stibnite with gangues of quartz and carbonates, with small amounts of jamesonite, berthierite, blende and auriferous pyrite, occur between Aranyidka and Rosenau."

(1)  
In Bohemia, "at Pricov ... kersantite dykes, occurring in the granite, are accompanied by veins of hornstone, rich in stibnite..... The stibnite is non auriferous ... and

(1) Beck. "Nature of Ore Deposits" - 1909, p. 336.

has been oxidized to stibiconite for a depth of 59 ft. ... Similar deposits occur at Pannau. .... These occur in mica schists and amphibolite near the granite of that locality." Truscott describes these occurrences in much the same manner and adds that "other veins in the district form a network <sup>(1)</sup> the character of the vein material being very similar to that of the country rock."

The Schonberg-Melechau deposits, 55 km south of Prague, are associated with kersantite dykes which cut the granite of that area. They are auriferous quartz-stibnite lodes, remarkable for their gold content which can frequently be seen with the naked eye. The gold content is too erratic to warrant mining on its account alone.

(c) Australia.

In 1913 Australia was producing 4% of the world's antimony. The chief centre of production is the Costerfield, Bendigo district, Victoria. Other areas of minor productive importance are at Broken Hill and Hillgrave districts New South Wales, and also insignificant showings in Queensland. Although the Victorian field is the most important, the writer could not obtain any detailed report on this. Such reports as were obtainable stated that in the Costerfield district, Victoria, stibnite occurred in veins associated with gold. Mr. G. Smith <sup>(2)</sup> gives a detailed description of the Broken Hill area.

<sup>(3)</sup> Antimony occurs in the Console Mine, Broken

(1) Truscott "Ore Deposits" Vol. 2, 1914, p. 379.

(2) Ore Deposits Console Mine, Broken Hill Aust. Trans. Am. Inst. Min. Eng. Vol. 26-1896, p. 69.

(3) Same as reference No. 2.

Hill district, New South Wales. The country rock consists of gneisses and schists of pre Cambrian age. The deposits occur in well defined and persistent fissures cutting the gneisses and schists at large angles to the planes of schistosity. At the surface the main fissure dips about  $20^{\circ}$  but lower it flattens out and then steepens almost to vertical. The ore is confined to areas of amphibolite schist, and the pay shoots occur at the intersection of small cross veins with the main fissure.

The primary minerals of the main vein are calcite and siderite as gangue and stromeyerite  $(Ag,Cu)_2S$  dyscrasite  $(Ag,Sb)$  and tetrahedrite. The cross veins consist of pyrite and zinc blende in a quartz gangue. A small vein of cobaltite is usually found in association with the main fissure.

Heavy oxidation has occurred resulting in the oxidation of the minerals to a depth of 130 feet or more. The gangue mineral calcite has been leached out and deposited as a sludge lower down. The siderite has been oxidized to limonite and this forms the main gangue mineral within the oxidized zone. The metallic minerals have altered to cervantite and cerargyrite and have suffered little transportation.

The foregoing antimony deposits have been described in the order in which their respective countries supply the world's demand for antimony. In the following discourse the antimony deposits of the various countries are arranged in a geographical association and sequence and not in the order of their productive importance. Some may produce up

to 1% or more of the world's total antimony output, while others are non producers. This is not due entirely to such deposits being of too poor a quality to be considered as ores of antimony, but to artificial modifications as the high cost of labor and unfavorable physical conditions.

(f) Germany.

"At Bohmsdorf<sup>(1)</sup> and Wolfolgen ... are quartz veins carrying stibnite with minor amounts of zinc blende, plumose stibnite, pyrophillite and iron spar." At Bruck, on the Ahr, stibnite is found in fissure veins, and to some extent as impregnations along the bedding planes of Paleozoic greywacke slates. The minerals present are quartz, siderite, dolomite, pyrite and stibnite.

Antimony ores occur at Uentrop<sup>(2)</sup> as bedded deposits in folded contorted and faulted limestones along the limbs of an anticline. The ore is stibnite and "forms sheets and rods extending outward nearly to the limiting surface of the strata, or occurs interspaced with the rock in small particles". At Nuttlar the stibnite occurs as nests in siliceous shales and black clays associated with sandstones. The epigenetic nature of these two deposits is shown by the association of facts.

"An interesting deposit is that at the Jost-

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(1) Beck "Nature of Ore Deposits," 1909, p. 336.

(2) " " " " " " p. 520, also Truscott "Ore Deposits" Vol. 2, 1916, p. 1188, 784. World Atlas of Commercial Geol. U.S.G.S. 1921.



(1)  
 Christian Mine ... in the Hartz, where a lode, something more than 1 metre wide ... consists of prismatic stibnite, together with federerz and lead stibnite; while ziendererz, boulangierite and wolfsbergite are less common .... The gangue consists of strontianite, calcite, barite, selenite and fluorite."

(g) Russia.

(2)  
 There is a deposit of antimony and lead-antimony ores in the Ural region and also in the Amur province, Siberia.

(h) Norway.

A deposit of antimony is known at Svenningdal, Norway.

(i) Portugal.

Stibnite deposits occur in Portugal at Oporto, Casa Branca, Alcoutim and San Pedro da Cova, some of which are auriferous. There is a small antimony production at Oporto.

(j) Spain.

Stibnite deposits are known in many parts of Spain, but under normal conditions there is no production.

(k) Italy.

The antimony deposits of Italy occur in Southern Sardinia, Piedmont, Tuscany and Sicily. The pre war output was small and came entirely from Southern Sardinia. During the war Tuscany and Sicily also produced.

(3)  
 In Sardinia at Su Suergiu, antimony occurs

(1) Truscott "Ore Deposits", Vol.2,1916, p.779.

(2) World Atlas of Commercial Geol. U.S.G.S. 1921.

(3) Truscott "Ore Deposits", Vol.2,1916,p.783.

in graphitic schists and calc-phyllites, of presumably Silurian age. The stibnite occurs in lenticular masses, associated with pyrite and scheelite in a calcite gangue. In Piedmont stibnite is associated with jamesonite, tetrahedrite and pyrite in quartz veins striking parallel to the schistosity of the enclosing rocks.

Antimony is found in Tuscany at Pereta, San Martino and Monte Anicata. "A noteworthy deposit of antimony occurs at Pereta, South Tuscany ... It consists of a mass of crushed white quartz" cutting Tertiary sediments of Eocene and Miocene age. "The stibnite occurs in the quartz as stringers and pockets ... associated with sulphur ... The sulphur bearing quartz is occasionally seen coated with a crust of stibnite, which in turn is studded with small crystals and aggregates of sulphur." The cinnabar-antimony deposits of San Martino and Monte Amiata are genetically connected with Quaternary volcanism.

The antimony deposits of Italy vary from deep seated contact metamorphic or high temperature veins to near surface deposition associated with volcanism and sulfotario action. An example of the first condition is shown by the association of stibnite with scheelite in Sardinia, while the occurrence of cinnabar and free sulphur in Tuscany is representative of the latter mode of deposition.

(1) Serbia.

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- (1) World Atlas of Commercial Geol. U.S.G.S. 1921.
  - (2) Beck, "Nature of Ore Deposits" 1909, p.337.
  - (3) Origin of Cinnabar-Antimony deposits, Tuscany, Abst. Fed. Inst. of Min. Eng., Vol. 19, 1899-p.484.

In Serbia antimony deposits occur in the districts of Kostainik, Zajassa and Allochar. The geology of the Kostainik district consists of laminated ~~and~~ Triassic limestones, conformably overlain by soft clay slates and in part by clastic greywacke slates. These rocks were folded and then intruded by biotite-trachytes as dykes, sheets and stocks, and perhaps covered by effusive flows of the same rock. "The antimony deposits are intimately connected with these igneous rocks."<sup>(1)</sup>

The deposits occur in three forms - (1) As stringers of quartz, calcite and stibnite in the altered trachyte; (2) As fissure vein deposits in the slates; (3) as replacement deposits in limestone along the slate limestone or trachyte limestone contact.

The vein material consists chiefly of quartz and stibnite with its oxidation products. No other metallic minerals occur. In type 2 the fissure is slightly over three feet thick and consists of hanging and foot wall stringers with transverse veinlets between the two through the vein filling. The foot wall is always the richest, while the hanging is almost barren. In type 3 the vein matter is fine granular quartz with intergrown stibnite. The hanging wall, formed either by slate or trachyte, is regular, whereas the foot wall, while generally following the stratification, is often irregular, showing unequal replacement of the limestone.

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(1) Beck. Nature of Ore Deposits. 1909. p.578-581.

"It is probable that the occurrence at  
 (1) Allchar in Macedonia .. is of metasomatic origin. The hanging wall of this deposit consists of mica schist, the foot wall of dolomites and limestone. The ore occurs in stringers or lenses without gangue, together with arsenic ores. The width of solid ore may at times be as much as 1.50 m., while the occurrence has been proved for a length of 4 kilometers. Near the deposit the dolomite has been highly altered under formation of sulphur and selenite. A portion of the ore consists of realgar and orpiment."

The antimony mineral present is not stated. The realgar and orpiment may be of primary deposition, in which case the presence of free sulphur suggests close association with volcanic activity. The realgar and orpiment might also be secondary as oxidation products of "arsenic ores" and in the same way the sulphur could be produced by the oxidation of a sulphide mineral and the reduction of calcium sulphate (2).

(m) Asia Minor and Turkey.

Antimony deposits occur pretty well distributed throughout Asia Minor (3) in Brussa, Smyrna and Siwas. In Smyrna the deposits are worked at the Rozsdan, Aiden, Geramos and Kordelio Mines. The most important producing district is Murat Dag. The deposits are stibnite occurring in fissure

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- (1) Truscott, "Ore Deposits" Vol. 2, 1916, p. 784.
  - (2) Aguilera-Trans, Am. Inst. Min. Eng. Vol. 32, 1902, p. 508.
  - (3) Eng. & Min. Journ. Vol. 84, 1907, p. 688. Truscott, "Ore Deposits" Vol. 2, p. 783; World Atlas of Commercial Geol. U.S.G.S. 1921.

veins with quartz gangue and pyrite. At Karahissar, argentiferous lead antimony ores occur.

(n) Algeria.

The antimony deposits of Algeria<sup>(1)</sup> occur at Djebel-Hamimat and Sidi-Rgheiss. They are found in steeply dipping limestones and slaty marls, chiefly along the limestone-marl contact, and to some extent disseminated in the shales. The ore is either solid crystalline or disseminated and occurs as irregular masses in the limestone roughly parallel to the bedding planes but not confined to any definite horizon.

The ore at present consists in part of a compact white antimony oxide and in part of crystalline senarmonite in association with oxidized zinc ore with some galena and cinnabar. Small amounts of the original stibnite still remain. There are no gangue minerals, but fragments of limestone, encrusted with ore, are often found.

These deposits represent metasomatic replacements in limestones. The original ore was stibnite in association with sphalerite, galena and cinnabar. The stibnite and sphalerite have been subsequently oxidized to the present antimony and zinc oxides, while the galena and cinnabar have remained. The temperature of original deposition probably varied from intermediate to low temperature.

(1) Beck "Nature of Ore Deposits" 1909. p.521; Truscott.  
"Ore Deposits" Vol.2, 1916. p.1189.

## (o) South Africa.

In South Africa antimony deposits occur at Gravelotte, Murchison Range, Transvaal, along the Transvaal Swaziland border, and in Southern Rhodesia.

(1)  
At Gravelotte the country rock consists of schists intruded by granite. Along the Murchison range diorite and basalt have intruded the schists, apparently parallel to their planes of schistosity. Younger dyke rocks also occur. The association of the older dioritic dykes points to their genetic relation to the ore.

The antimony bearing deposits are quartz veins with an abundance of gold bearing stibnite, which in places is oxidized. The veins occupy irregular fissures varying from 1 to 10 ft. in width.

(2)  
In 1917 the Rhodesian Munitions and Resources Committee reported that stibnite in Rhodesia occurred as two types.

(1) "The sporadic gold bearing type characterized by its sporadic distribution in quartz veins and schist bodies. This is of granular texture and forms stringers, patches and large pockets, or it may be disseminated through a schist body in the form of minute crystals. In the last mentioned instance the mineral is the double sulphide of lead and antimony."

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- (1) Stewart, Trans. Fed. Inst. Min. Eng. Vol. 17, 1898, p. 402-403.  
(2) Eng. & Min. Journ. Vol. 104, 1917, p. 471.



(2) "The type which forms definite veins sometimes free of quartz .. The veins are of coarse stibnite which weathers to a pale yellow ochre."

(p) New Zealand.

Although antimony occurs in a number of localities throughout New Zealand this country has not been in the producing antimony market since 1910. Deposits of stibnite are found in Central and Western Otago; Endeavor Inlet, North Westland; Reefton and Westport, Nelson; Collingwood; Queen Charlotte Sound, Marlborough; and Hauraki, Auckland.

(1)  
At Carrick Range, Western Otago the country rock is flaky mica schist passing into a phyllite. The deposit occurring in a shear zone, varies from a true quartz vein through all stages to a vein breccia cemented by quartz; the fragments of which show various degrees of alteration. The sheared zone varies in width from 2 to 4 feet and may be filled entirely with quartz, or the quartz may occur as small veins along both walls or one wall only. The wall rock and quartz are both slickensided showing that secondary movement has occurred after mineralization. The ore is stibnite with associated gold and silver values. Near the surface the stibnite has been oxidized to cervantite. The age of these deposits is younger than late Paleozoic and older than Pliocene. No igneous rock outcrops in the vicinity.

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(1) Parke, N.Z.G.S. Bull #5, 1908, p.66.

(1)  
At Endeavor Inlet the country rock is submetamorphosed sandstone with interbedded slates. The deposits occur along the slickensided hanging wall of slate bands and coincide to the strike and dip of the strata. The ore is stibnite in a quartz gangue, and is found in irregular lenses and pockets varying in width from a few inches to one foot or more. A vein of stibnite crosses an adjacent stream and considerable alluvial stibnite has been recovered a short distance below the vein.

(2)  
In North Westland, the antimony of the district occurs as stibnite in a quartz vein traversing argillites and greywackes. Considerable gold is associated with the stibnite and the deposit may be of more importance for its gold values than its antimony content.

(3)  
At Queen Charlotte Sound, Malborough, auriferous stibnite is found in a fine grained greenish schistose rock. The chief mineral is stibnite with minor amounts of quartz disseminated through the ore. "With the antimony ore are found loose blocks of olivine, with chromium ore, compact hornblende rock and a white and green chert."

(4)  
In the Hauraki district, Auckland, the country rock in association with the antimony deposits consists of volcanic breccias and flow rocks of Tertiary age. The

(1) Parke, N.Z.G.S., 1888-89, p.60, also p.33.

(2) Bull.13, N.Z.G.S., 1911, p.83.

(3) G.J.Binns, Trans.Fed.Inst.Min.Eng.Vol.4, 1892-93, p.59.

(4) C.Fraser, N.Z.G.S., Bull #10, 1910.



deposits occur along fault planes and shear zones which have a tendency to follow the contact of the breccias and andesitic flows. At Una Hill the deposits are replacement veins entirely within the andesite which has been subjected to decided propylitic action along the walls of the veins.

The stibnite occurs in a quartz gangue in association with pyrite, chalcopyrite, zinc blende, pyrargyrite and gold. The ores are mined for their gold content, the stibnite being accessory.

The veins occur in Tertiary volcanic rocks so that their age is younger than these extrusives. No definite statement is made as to the origin of the minerals, but from the context of the report it would seem that the mineralization was genetically associated with the intrusion of andesitic dykes.

From the above description it is hard to draw any definite conclusions as to the temperature of deposition of the antimony deposits of New Zealand. In the Hauraki district, more detailed information is given and this points to mineral deposition from hot ascending solutions under near surface conditions. Lindgren states, under "Replacements at Intermediate Temperatures;" <sup>(1)</sup> "In deposits which have been formed by hot waters near the surface where the rocks are permeable, the incipient alteration of igneous rocks is often widespread with alteration of the ferrous minerals to chlorite, calcite or epidote (propylitization)".

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(1) Lindgren. "Mineral Deposits" 1919, p.478.

This is one of the most common types of alteration following explosive igneous activity and effects "mainly andesites and basalts, more rarely rhyolites".<sup>(1)</sup> In describing the gold quartz veins in andesites of Transylvania, Hungary, Schumacher considers that the propylitization was distinctly earlier than the veins and independent of them.

Lindgren describes these deposits of Hauraki under "gold-quartz veins in andesites" and says, "Park<sup>(2)</sup> states that the veins do not continue into the underlying Jurassic shale and they are thus limited to the thickness of the lava flows in which they occur. ... The principal ore mineral is gold alloyed with 30%-40% silver, but some pyrite, chalcopyrite, zinc blende, galena, stibnite and pyrargyrite also occur."

(q) Borneo.

During the war old mines were reopened and ore was shipped to England. The deposits occur on the north end of the island in Sarawak, and consists of quartz veins containing stibnite which has been oxidized to native antimony and various antimony oxides.

(r) Japan.

Very little antimony ore is mined in Japan. The antimony exports of this country is due chiefly to the exploitation of the Chinese deposits. Either ore or crude antimony is imported from the Chinese mines and then refined and exported as regulus.

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(1) Lindgren "Mineral Deposits" 1919, p.478.  
 (2) " " " " p.508.

The antimony deposits of Japan occur along the southern bend of Japan, especially along the outer border. These are quartz stibnite deposits which are found in Paleozoic and Mesozoic sediments near their contact with quartz porphyry intrusions or within the intrusion itself. Occasionally the deposits are found in crystalline schists, as on the island of Shikoku, and also in Tertiary rocks.

(s) Peru.

The antimony mines of Peru were dormant from 1907 until 1915 when they were reopened and high grade ore was shipped to Japan. The deposits occur in the department of Puno, Southern Peru where the stibnite is found in replacement deposits in limestones. Antimony occurs abundantly all over the Province of Cajatambo<sup>(2)</sup> and is invariably associated with silver. The stibnite is found in fissure veins associated with pyrite, tetrahedrite, bournonite, panabase and less commonly with pyrargyrite and stephanite. The copper antimony sulphide famatenite ( $3\text{Cu}_2\text{S} \cdot \text{Sb}_2\text{S}_5$ ) occurs at Cerro de Pasca.

(t) Bolivia.

Many small high grade deposits of stibnite occur in the southern part of the Potosi department. The ores are mined and shipped to England.

(u) United States.

Although United States is one of the largest antimony consumers, there is no home production of antimony ore.

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(1) U.S.G.S. World Atlas of Commercial Geol.. 1921.

(2) Abst.Fed.Inst.Min.Eng.Vol.25,1902,p.776; also Vol.36,1908,p.766.

TABLE 2.

Antimony imported into the United States in 1919-1923<sup>a</sup>

(General imports)

|                 | Antimony ore |                  |          | Antimony metal b |           |
|-----------------|--------------|------------------|----------|------------------|-----------|
| Country         | Short tons   | Antimony content |          | Pounds           | Value     |
|                 |              | Pounds           | Value    |                  |           |
| 1919            |              |                  |          |                  |           |
| Canada .....    | .....        | 28               | \$10     | 2,308,880        | \$167,764 |
| Chile c .....   | 47           | 49,624           | 6,312    | .....            | .....     |
| China d .....   | 455          | 362,326          | 23,936   | 7,847,840        | 459,613   |
| England .....   | .....        | .....            | .....    | 90,048           | 8,803     |
| Hongkong d ...  | 4            | 4,510            | 493      | 68,320           | 3,949     |
| India(British)  | .....        | .....            | .....    | 224,000          | 10,976    |
| Japan d .....   | .....        | .....            | .....    | 2,953,994        | 159,091   |
| Mexico .....    | 297          | 219,048          | 11,332   | 757,076          | 60,571    |
| Panama .....    | 2            | 1,200            | 99       | .....            | .....     |
| Peru .....      | 74           | 90,726           | 7,345    | .....            | .....     |
|                 | 879          | 727,462          | 49,527   | 14,250,158       | 870,767   |
| 1920            |              |                  |          |                  |           |
| Bolivia c ..... | 388          | 335,061          | \$22,941 | .....            | .....     |
| Canada .....    | 132          | 19,457           | 2,179    | 225,272          | \$19,111  |
| Chile c .....   | 162          | 152,276          | 11,963   | .....            | .....     |
| China d .....   | 420          | 450,293          | 14,185   | 21,564,851       | 1,218,802 |
| England .....   | .....        | .....            | .....    | 125,539          | 14,638    |
| France .....    | 467          | 315,861          | 10,605   | .....            | .....     |
| Hongkong d ...  | 75           | 10,200           | 4,556    | 706,156          | 44,909    |
| Japan d .....   | .....        | .....            | .....    | 2,325,303        | 177,816   |
| Panama .....    | 65           | 80,293           | 3,856    | .....            | .....     |
|                 | 1,709        | 1,363,441        | 70,285   | 24,947,121       | 1,475,276 |
| 1921            |              |                  |          |                  |           |
| Bolivia c ..... | 45           | 46,600           | 2,450    | .....            | .....     |
| Chile c .....   | 49           | 54,401           | 3,334    | .....            | .....     |
| China d .....   | .....        | .....            | .....    | 20,530,079       | 672,501   |
| England .....   | .....        | .....            | .....    | 302,457          | 14,586    |
| Germany .....   | .....        | .....            | .....    | 45               | 7         |
| Hongkong d ...  | 119          | 95,106           | 5,898    | .....            | .....     |
| Japan d .....   | .....        | .....            | .....    | 320,750          | 10,027    |
|                 | 213          | 196,107          | 11,682   | 21,153,331       | 697,121   |

TABLE 2.

Antimony imported into the United States in 1919-1923-Continued.

| Country             | Antimony ore |                  |        | Antimony metal b |         |
|---------------------|--------------|------------------|--------|------------------|---------|
|                     | Short tons   | Antimony content |        | Pounds           | Value   |
|                     |              | Pounds           | Value  |                  |         |
| 1922 c              |              |                  |        |                  |         |
| Canada .....        | .....        | .....            | .....  | 8,960            | 364     |
| China d .....       | .....        | .....            | .....  | 16,976,726       | 562,181 |
| England .....       | .....        | .....            | .....  | 45,474           | 3,335   |
| France .....        | .....        | .....            | .....  | 22               | 4       |
| Germany .....       | .....        | .....            | .....  | 515              | 65      |
| Hongkong d .....    | .....        | .....            | .....  | 627,424          | 30,531  |
| Netherlands .....   | .....        | .....            | .....  | 84,744           | 3,813   |
|                     |              |                  |        | 17,743,865       | 600,293 |
| 1923                |              |                  |        |                  |         |
| Australia ...       | (f)          | 113,864          | 4,901  | .....            | .....   |
| Belgium .....       | .....        | .....            | .....  | 38,715           | 2,420   |
| Bolivia e ...       | (f)          | 176,368          | 3,937  | .....            | .....   |
| Canada .....        | .....        | .....            | .....  | 55,740           | 3,848   |
| Chile e .....       | (f)          | 1,169,784        | 25,644 | .....            | .....   |
| China d .....       | .....        | .....            | .....  | 13,185,898       | 558,771 |
| England g ...       | (f)          | 1,340            | 102    | 1,410,198        | 99,927  |
| France .....        | (f)          | 111,026          | 1,020  | .....            | .....   |
| Germany g ...       | (f)          | 1,800            | 906    | 750,555          | 44,953  |
| Hongkong d ..       | .....        | .....            | .....  | 73,762           | 3,385   |
| Italy .....         | .....        | .....            | .....  | 60               | 9       |
| Japan d .....       | .....        | .....            | .....  | 56,000           | 2,074   |
| Mexico .....        | (f)          | 519,913          | 8,211  | .....            | .....   |
| Straits Settlements | .....        | .....            | .....  | 56,000           | 2,682   |
|                     | (f)          | 2,094,095        | 44,721 | 15,626,928       | 718,069 |

c Imports credited to Chile originated mainly in Bolivia.

d Nearly all the imports of antimony ore and metal from Hongkong and Japan are of Chinese origin. Some of the material credited to other countries is possibly also of Chinese origin, having been transhipped in a foreign port.

e No ore was imported in 1922.

f The Department of Commerce does not give the figures for imports of antimony ore in 1923.

g England and Germany are the only countries from which imports of both ore and metal were received. The total imports from England were 1,411,538 pounds of antimony metal, valued at \$100,029; and those from Germany were 752,355 pounds, valued at \$45,859.



This country draws its main supply of antimony from China in the form of regulus; and to some extent as crude antimony and ore from China, Mexico and other countries. Table 2.<sup>(1)</sup> gives the imports of antimony to United States from the various countries during the post war years of 1919 - 1923.

Besides this the United States consumes 2100 tons of antimony contained in the antimonial lead and silver ores of domestic smelting, and 3500 tons of antimony recovered from alloys, scrap, dross and waste materials.

The principal districts in which antimony occurs are Nevada, California, Alaska, Arkansas, Utah, Idaho and Washington.

#### Arkansas.

The antimony deposits of Arkansas are found chiefly in the Sevier County. Several reports have been written on these deposits, and the available reports state<sup>(2)</sup> that the antimony occurs as stibnite in quartz veins, in association with zinkenite, jamesonite, galena, orpiment, bismuthenite, pyrite, and minute amounts of chalcopyrite. Oxidation has taken place to a depth of 30 feet or more with the formation of cervantite and bindheimite.

In his report on the antimony deposits of Northern Sevier County, E.H.Shriver<sup>(3)</sup> states that they occur in

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(1) Mineral Resources of U.S. 1923 Part 1 p.288-289.

(2) C.P.Williams - Trans.Am.Inst.Min.Eng.Vol.13 1875.p.150.  
C.E.Wait " " " " " 1879-80 p.42.

(3) E.H.Shriver Min. & So. Press Vol.114 1917 p.920.

folded Carboniferous sandstones and argillaceous shales metamorphosed to slates. "The stibnite ore was formed by the replacement of the shales and slates .... The fine grained sandstone proved impervious to the hot waters and acted as an impounding dam..... The ore bearing rock is shale or slate, rarely, if ever the sandstone. The hanging wall is decomposed slate in all cases, and the foot wall is a fine grained sandstone upon which the solutions flowed."

Some of the veins show banded structure. The vein filling is quartz and stibnite both being deposited simultaneously. "The ore is cemented to the foot wall and varies from a thin streak to 30 inches in width while the full lode is from 2 feet to 5 feet in width."

The ore is stibnite which has been oxidized, near the surface, to cervantite. The stibnite is either coarse crystalline or compact. Jamesonite was also found in one place.

From the description of the deposits and the diagrams accompanying the above report it seems more likely that the overlying shales acted as a dam and the solutions percolated along the shale-sandstone contact, replacing the latter.

In 1922 G.F. Mitchell<sup>(1)</sup> describes the deposits of Servier County as vein fillings in fault zones in steeply dipping Paleozoic shales and sandstones. The mineralized zones vary in width from a few inches to 4 feet or more and closely follow the strike and dip of the sediments. The wall

(1) Eng. & Min. Journ. Vol. 114 - 1922.

rocks are slightly replaced, but the veins are banded and the ore occurs in lenses and pockets. While stibnite occasionally occurs in segregated masses it is usually found to be disseminated through the gangue which is chiefly quartz with some calcite and occasional fragments of shale and sandstone. Mitchell believes the ore to be genetically related to igneous dykes found in the vicinity.

Other reports have been written of the  
 antimony deposits in Arkansas by F.L.Hess,<sup>(1)</sup> J.C.Branner,<sup>(2)</sup>  
 F.D.Dunnington,<sup>(3)</sup> and B.Comstock,<sup>(4)</sup> but these were not available  
 California.

#### San Benito County.

Antimony, in association with cinnabar, occurs at Antimony Hill in the N.E. corner of the San Benito County California.<sup>(5)</sup> The rocks are sandstones at the eastern foot of the mountain, and serpentine on the western slope near the summit. The minerals occur in slates and are found both on the eastern and western slopes. The gangue is quartzose and contains the stibnite and cinnabar; the deposits on the east have more cinnabar and less stibnite than those on the west.

#### Kern County.

Four miles south of Hot Springs, Erskine Creek

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- (1) F.L.Hess, U.S.G.S. Bull. 340D, 1907.  
 (2) J.C.Branner Annual Rep. Ark. Geol. Survey Vol. 1, 1888, p. 136.  
 (3) F.D.Dunnington Am. Assn. for Adv. of Sc. #26, 1878, p. 181.  
 (4) B.Comstock Annual Rep. St. Geo. Ark. 1888, Vol. 1, p. 136 and 216.  
 (5) E.B.Preston Calif. St. Min. Bur. 1891-92, p. 371.



(1)  
in Kern County. Antimony occurs in quartzite associated with a porphyritic rock. Native antimony occurs in nodules varying in weight from 1 ounce to 300 pounds and is coated with white oxide and clay. Associate veins carry stibnite. No associated minerals are mentioned with the native antimony or stibnite.

#### Monterey County.

(2)  
Stibnite occurs in Monterey County at the Los Berros Gold Mines. The veins are quartz near the contacts of slates and serpentine.

#### Calaveras County.

(3)  
Antimony ore was discovered on Esperanza Creek, Calaveras County, California.

#### South Dakota.

The ores of the Maitland properties occur immediately above the Cambrian quartzites. Only the oxidized ores have been treated, in a cyanide process, and these yield pyrite and pyrrhotite in about equal amounts along with some arsenic, copper, traces of antimony and tellurium and considerable quantities of bismuth.

#### Utah.

(4)  
Antimony occurs in Iron County, Utah.

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- (1) W.L.Watts, Calif. St. Min. Bur. 1891-92, p. 237.
- (2) E.B.Preston, " " " " " " p. 261.
- (3) Mining and Scientific Press Vol. 114, 1917 p. 312.
- (4) Kemp, Ore Deposits of U.S. & Can. 1906, p. 411.
- F.L.Hess, U.S.G.S. Bull 340D 1907, p. 253.
- W.P.Blake, Rep. on Antimony Dep. of S.Utah 1881.
- D.B.Huntley, "On Utah" U.S. 10th Census Vol. 13, p. 463.

Disseminations of stibnite, following the stratification, are found in sandstones and conglomerates. Very large individual pieces of stibnite have been found. Eruptive rocks overly the sandstone and Blake thinks that the ores have crystallized from descending solutions originating in the eruptive rocks. Lindgren (1) draws an analogy between these deposits and those now forming at Steamboat Springs, Nevada, which will be described later.

#### Nevada.

Antimony occurs in Nevada in the National and Arabia districts and at Steamboat Springs.

The National Mining District (2) is located on the Santa Rosa Range. The southern and larger part of this range is made up of highly folded clay slates, calcareous slates and limestones trending north, parallel to the range. The north or northeastern section is overlain by volcanic eruptives such as basaltic flows, breccia, latites, trachytes and rhyolites.

There are two principal classes of mineral deposits: 1. "Gold and silver bearing veins that occur in or near the Tertiary volcanic rocks and that are of Tertiary or in part of Quaternary age."

2. "Gold and silver bearing veins that occur in the sedimentary rocks and in the post-Triassic granular rocks intruding into the sediments and that are probably of late Mesozoic age."

The old Mesozoic mineralization is generally in quartz veins

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(1) Lindgren, Trans. Am. Inst. Min. Eng. Vol. 36, 1906, p. 27.

(2) Lindgren, U.S.G.S. Bull. 601, 1915.

although rarely they are replacement deposits in limestones and lime shale. These veins carry both gold and silver but no antimony minerals.

#### Tertiary Mineralization:

In the northern section of the Santa Rosa Range the sediments are covered by volcanic extrusives consisting of basalts, latites, trachytes and rhyolites. The basalts are the most common; the rhyolite was extruded near the close of the volcanic period and is consequently high in the series, but is also covered with basalts. This rhyolite flow is the important rock in the district as the mineralization is due to the effect of ephemeral springs related to the rhyolite.

The veins of the National District are distinctly later than any other rocks and are of the narrow fissure types. They trend northerly and have a steep dip either to the east or west. The wall rock has been subjected to propylitic alteration, producing some pyrite, calcite, a little sericite and adularia, and chlorite. This alteration is not extended over wide areas.

The veins vary in width from 1 to 5 feet. They consist of sheared rock and have a well defined foot wall. Seams of quartz occur along the foot, hanging or intermediate walls. This quartz is symmetrically banded, fine grained and vuggy; crystals of quartz line the vugs. "This fine grained symmetrically banded quartz with open vugs together with the scarcity of pyrite, the consistency of stibnite and the presence of cinnabar, in one instance, point strongly to near surface deposition."

The mineral deposition took place from hot thermal ascending solutions. The characteristic mineral is stibnite which occurs in varying amounts in all veins. The stibnite may be fibrous and confined to the margins of the quartz or it may be in the center of the vein. It also occurs as fibrous well crystallized aggregates in the quartz or as acicular crystals encrusting the quartz crystals in the vugs. Associated minerals are chalcopyrite, pyrite, arsenopyrite, zinc blende, galena, silver and gold; cinnabar was noted in one instance. These minerals occur as fine grains along the margin of the veins. It was noted that when the stibnite was relatively high the gold and silver values were low, whereas, if the stibnite was scarce the gold and silver values were somewhat higher.

The gangue is predominantly quartz either as a massive fine grained variety or crystallized in vugs. No calcite, barite or fluorite are found as vein filling.

#### Secondary Minerals:

Secondary sulphides such as marcasite, stibnite, realgar and orpiment occur below the present water level. The predominant secondary sulphide is marcasite and is found in varying quantities everywhere. The secondary stibnite occurs either as flat bundles of acicular crystals in the joints and fissures or as capillary coatings on the quartz crystals in the vugs. Lindgren<sup>(1)</sup> states that due to the predominance of marcasite these secondary sulphides were most likely produced by

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(1) U.S.G.S. Bull. 601, 1915, p.45.

cold ascending solutions rising along the vein long after their formation. Realgar and orpiment are most likely the result of the oxidation of arsenopyrite. The stibnite oxidizes to a yellow earthy material. No secondary gangue minerals occur.

Although these deposits may have been formed under near surface conditions their temperature of deposition could still be in the intermediate or even high temperature zone. An example of high temperature deposits formed near the surface is given by the tin deposits of Mexico as described by Truscott.<sup>(1)</sup> Lindgren<sup>(2)</sup> states that physical conditions differing slightly from those at the actual surface will evidently produce crystallized minerals of normal habit and form. Propylitization is the result of rock alteration by ascending thermal waters of intermediate temperatures. Considering these facts and the associated minerals it appears reasonable to conclude that the stibnite was deposited at intermediate temperatures.

The Antimonite Silver-Lead Veins of the Arabia District, Nevada:

The prevailing rock of the Arabia District<sup>(3)</sup> is granodiorite which contains many black and irregular masses of thoroughly metamorphosed sedimentary rock. The granodiorite consists of quartz, feldspar and biotite of which the feldspar and biotite have become sericitized and gives the whole mass the appearance of an apatite. The sediments are chiefly metamorphosed shales

(1) Truscott, "Ore Deposits" Vol. 1, 1914, p. 447.

(2) Lindgren, Trans. Am. Inst. Min. Eng. Vol. 36, 1906, p. 27.

(3) A. Knoff, U.S.G.S. Bull. 660 H., 1918.

(hornfels); overlying all are rhyolites probably of Miocene or Pliocene age.

The ore bodies are fissure veins in the granodiorites and hornfels. The fissures are regular and have definite walls in the granodiorite but upon entering a large body of hornfels they fray out and form narrow stringers. The richer veins are filled with solid ore but the leaner ones are made up of ore and coarse milkwhite quartz which contains inclusions of tourmaline.

The ore as now found consists of argentiferous bindheimite (hydrous antimonate of lead) with associated plumbojarosite (basic sulphate of lead and ferric iron) scorodite (hydrous ferric arsenate) cerussite, gypsum and quartz. The bindheimite is of two varieties; one a deep yellowish brown amorphous variety of high brilliant pitchy lustre, and the other, a yellowish compact earthy variety showing divergent columnar structure which is a pseudomorph after its original mineral.

This deposit is an exceedingly highly oxidized one. Remnants of the primary minerals are occasionally found and consist of fibrous jamesonite arsenopyrite and a little chalcopyrite. The oxidation of the jamesonite has resulted in the formation of the bindheimite, cerussite and plumbojarosite while the arsenopyrite has been oxidized to scorodite. The oxidation of these original sulphides would most likely produce sulphuric acid which would dissolve the silver and carry it down. This would be precipitated by the primary sulphides lower down, and result in a zone of secondarily enriched silver. Antimony and

arsenic are only slightly soluble and would not be moved. There would, however, be an illimination of sulphur.

The paragenesis of jamesonite shows that it is common in high temperature ore deposits as shown by its occurrence in a contact metamorphic deposit at Zimapan, Mexico, and in tin bearing veins in Bolivia. The association of tourmaline in this deposit substantiates this evidence.

Knoff is inclined to place the age of the granodiorite intrusion in the early Cretaceous. "The rhyolite is far younger in age than the ore deposits and in places caps granodiorite and the enclosed masses of hornfels."<sup>(1)</sup> He places the age of these rhyolites in the Miocene or Pliocene.

#### Steamboat Springs, Nevada:

The waters of Steamboat Springs<sup>(2)</sup> issue from a fissure in granodiorite and are at a temperature of about 80° C. On analysis they give ferric oxide, antimonious and arsenious sulphide, mercuric and cupric sulphide, lead, gold and silver. At the base of a basaltic cliff nearby, the waters have deposited a large amount of silicious and calcarious sinter stained red by the red metastibnite which has a nonmetallic lustre.

A few feet from the railroad station a shaft was sunk 30 feet. The first 25 feet are through sinter after which there exists a loose sandy gravel composed of well washed pebbles of granite and andesite. These gravels contain so much

(1) A. Knoff, U.S.G.S. Bull. 660H, p. 249.

(2) Lindgren, Trans. Am. Inst. Min. Eng. Vol. 36, 1906, p. 27.

hot water that operations were stopped.

An examination of the gravel showed that nearly every pebble had adhering to it small shiny prisms and particles of metallic lustre. These proved to be prisms of stibnite, bent and otherwise combined in radiating groups but generally without terminations. In the cracks and joints of the larger granite cobbles bunches of stibnite crystals occur. "With the exception of elastic magnetite the only other metallic mineral found in the gravel is pyrite which forms loose or intergrowing crystals of octohedral form sometimes combined with the cube."

"I believe it absolutely certain that the stibnite and pyrite have been deposited by the hot waters which permeate the gravel." On previous examination of the same locality, "The absence of ordinary minerals of metallic lustre indicated, in a way, a missing link in the chain of evidence to prove the deposition of ores from hot ascending waters; and this link is now supplied by the observations recorded above. . . . Physical conditions differing very slightly from those at the actual surface will evidently produce crystallized minerals of normal habit and form.

(v) Alaska.

There are some sixty-seven known occurrences  
(1)  
of antimony in Alaska distributed between southeastern Alaska and the Aleutian Islands. The main deposits are found in the Fairbanks District and the Seward Peninsula.

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(1) A.H.Brooks, U.S.G.S. Bull. 649. 1916; also U.S.G.S. Bull. 662, 1918.



### Geology.

The stibnite of Alaska is generally found in sedimentary rocks varying in age from lower Cambrian to upper Cretaceous and differing widely in their lithological characters. The stibnite is also found in gneisses, schists and in the intrusive rocks themselves, although in the latter case the veins are small and not continuous. The deposits, however, are generally found in the intruded country rock, not far from the igneous contact. With the possible exception of the galena stibnite type there are no contact metamorphic deposits. The stibnite always occurs in close association with granular acidic intrusive rocks belonging to the quartz diorite or monzonite groups or to the porphyritic phases of these types. These intrusions are either dykes or stocks and have produced but little metamorphism in the enclosing rocks.

### Classification of Ore Deposits.

- (A) Siliceous gold bearing stibnite deposits.
- (B) Stibnite cinnabar deposits.
- (C) Stibnite galena deposits.

#### Siliceous gold bearing stibnite deposits.

These may be either fissure veins or shear zone deposits. No definite line of demarcation can be made as the former often grade into the latter. Some shear zones show great persistency, are well defined and are traceable for several thousand feet.

The deposits vary in width from 2 to 5 feet, but are much wider in the shear zone type. They are irregular

along their strike, pinching and swelling frequently. The richer ore occurs in shoots or kidneys especially in the wider parts of the lode where it often extends from wall to wall. Small veins of lower grade ore connects these shoots. Rich lenses, irregularly distributed also occur.

The stibnite in the richer ores is usually fine granular but confused aggregates of acicular crystals also occur. These two types are often mixed. Besides the stibnite there may be varying amounts of galena, pyrite, arsenopyrite and small amounts of gold, grains of which are sometimes imbedded in the stibnite. Quartz forms the chief gangue mineral. This occurs as fine granular vitreous grains, many with crystal terminations, scattered through the ore. A milky quartz with associated feldspars also occurs but such represents old quartz veins which have been reopened and granulated with a subsequent introduction of stibnite. The vitreous quartz is typical of antimony ores. Some of the sulphides and maybe part of the gold belong to an early period of mineralization.

#### **Stibnite - Cinnabar Deposits.**

These deposits occur both in veins and in mineralized shear zones; the valuable minerals occurring in shoots and kidneys connected by small stringers. Banding is often well marked, and vugs, lined with quartz crystals, are common. In some cases the cinnabar is the primary mineral with the stibnite introduced later; in other deposits the cinnabar and stibnite are contemporaneous. The stibnite is in bladed crystals, columnar aggregates and, less common, in granular masses. Pyrite, as an accessory

mineral, is very scarce and some gold is common to all such deposits. Quartz is the only gangue mineral present and is vitreous and often idiomorphic. The percentage of quartz is higher than in the quartz gold bearing deposits.

From information at hand these deposits are associated with the same intrusive rocks as the auriferous quartz stibnite deposits but were formed at a shallower depth than the former, often near the surface, a genesis common to cinnabar deposits.

#### Stibnite - Galena Deposits.

These deposits appear to be replacements of crystalline limestone, but it is not certain whether the stibnite was contemporaneous with the galena, or belongs to a later epoch of mineralization.

An occurrence of stibnite in association with fluorite, in a rock now composed of scapolite, is recorded in the Lost River Basin of Seward Peninsula.

#### Vertical Distribution and Oxidation of the Ores.

From outcrops of veins, extending over 1000 feet in elevation, no change in mineralization was observed. Thus there is little probability that changes will occur sufficiently close to the surface to effect the value of the antimony deposits.

As a rule the antimony deposits of Alaska show very little oxidation. This is due to two primary factors:

(a) The ground covering the deposits is, in most cases, permanently frozen.

(b) Comparatively recent glaciation has re-

moved any previously existing oxidized zone.

#### Age of Mineralization.

The accumulative evidence favors Tertiary mineralization of stibnite. Where the mineralization is definitely known to be Mesozoic, there is no stibnite, with one exception in Southern Alaska where stibnite is recorded as a minor accessory mineral. All stibnite deposits, the age of which could be definitely established, belong to the Tertiary epoch of mineralization. In those deposits of doubtful age the probabilities favor the Tertiary epoch rather than the Mesozoic.

Two instances are known where stibnite occurs in placers. <sup>(1)</sup> In the Tolovana district a placer on Lillian Creek contains magnetite, ilmenite, picotite, limonite, cinnabar, scheelite, zircon, pyrite, stibnite and barite, in the order of their importance. The character of the concentrates shows that they have travelled only a short distance. In the Kantishna district a placer contains gold, quartz, galena, stibnite and black sand. The source of the minerals are the quartz veins outcropping on the ridges bordering the basin.

#### (w) Canada.

Antimony, as a commercial mineral in Canada, is somewhat rare. The only mines which have produced any tonnage of the metal are at West Gore, Hantz County, Nova Scotia, and Lake George, York County, New Brunswick. Besides these

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(1) U.S.G.S. Bull. 662-1918.

occurrences, antimony is also found in various other localities in Canada as in Southern Quebec, at Sault Ste. Marie, in British Columbia and in the Yukon Territory.

#### Nova Scotia.

Several veins of auriferous stibnite occur in the gold bearing series of West Gore, Hantz County. <sup>(1)</sup> The deposits are nearly vertical fissure veins, the vein filling being composed of slate, calcite and quartz cut by later quartz stringers. The ore generally follows the hanging wall of the fissure, which is clean cut; the foot wall is irregular and indistinct. The ore is often solid stibnite, or stibnite and quartz, varying in width from a few inches to seven feet. The associated minerals are pyrite, arsenopyrite, galena and gold. A varying amount of gold is always present and is most plentiful where stibnite predominates, except where cut by cross veins of quartz the main lead has no free gold.

#### New Brunswick.

"Native antimony and stibnite occur at Lake George, in the parish of Prince William, York County, New Brunswick. <sup>(2)</sup> ... The antimony ore occurs in quartz veins cutting slates and quartzites in the neighborhood of intrusive masses of granite and diabase. The native antimony is confined largely or solely to the upper portions of the veins."

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(1) G.A.Young, G.S.C. #1085, 1909, p.51-52.

(2) G.A.Young, G.S.C. " " p.52: also R.W.Ellis, G.S.C. #983, 1907, p.92.  
G.S.Parsons, Can.Min.Journ.Vol.45, 1924, p.984.

G. F. Kunz<sup>(1)</sup> describes the native antimony

as occurring at depths down to 100 to 150 feet. It occurs in pockets and lenses some of which contain upwards of one ton of native antimony in association with stibnite, valentinite and kermesite. The native antimony is either fine grained and compact, coarsely granular or in radiating masses of crystalline plates. In reference to these latter he says "The radiations seem to have massed about a common centre, as if the mineral had cooled or crystallized slowly from without."

The stibnite occurs either as massive, fine or very coarse crystalline aggregates in a quartz gangue. The valentinite is found in layers between the native antimony and is massive, granular or in radiating aggregates of crystals. The kermesite occurs as small tufts of crystals in cavities in the stibnite and native antimony, and also along the fracture planes of the latter mineral.

Lindgren and W. H. Emmons regard native antimony as probably if not invariably a secondary mineral derived from the oxidation of stibnite or other sulphide minerals of antimony. In this deposit the occurrence of the native antimony in the oxidized zone and in close association with valentinite and kermesite is in keeping with this theory. Other instances where native antimony occurs in oxidized ores of antimony are in Southern Quebec, Algeria, Kern County, California and Borneo.

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(1) G.F.Kunz. Am.Journ. of Sc. Vol.30,1885. p.275-277.

## Quebec.

The only occurrence of antimony in Quebec is at South Ham, Beauce County. <sup>(1)</sup> The district is underlain by Paleozoic strata resting on the Pre-Cambrian complex. The Paleozoic rocks have been folded, faulted and subjected to severe regional metamorphism and are now represented by shales, limestones and sandstones together with schists, slates and quartzites. In the vicinity of the antimony occurrences the schists and slates have been intruded by diabase dykes, part of which are now altered to serpentine. These dykes are probably of lower Devonian age, maybe later, and are genetically connected with the stibnite mineralisation.

This deposit is a contact deposit, the ores occurring mainly in the schists along their contact with the intrusive diabase and serpentine. "No distinct veins of any considerable width could be found in the present state of the workings, but the principal amount of ore seems to be in flakes along the cleavage planes of the schists. The proportion of the ore becomes greater as the contact is approached." The ore is native antimony with subordinate amounts of stibnite, kermesite and valentinite.

Stibnite occurs in the chlorite schists at Sault Ste. Marie. <sup>(2)</sup>

## British Columbia.

Antimony minerals are found rather widely

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(1) J.A.Dresser, G.S.C. S. 1909, p.197.

(2) J.Merritt, Trans.Fed.Inst.Min.Eng. Vol. 10, 1895, p.292.

distributed throughout British Columbia. Occurrences are noted in the districts of Yale, Slooan, Kamloops, Lillooet, Chilco and Tatlayoko Lakes, Skeena River, Portland Canal and Atlin Lake.

Stibnite is found at several points in the Yale district and is often in association with silver ores.

At the Alps-Alturus and Blue Lake claims in the Slooan May area <sup>(1)</sup> stibnite is found in Carboniferous rocks. The mineralization is genetically related to the Nelson granite of Jurassic age.

#### Kamloops.

On Copper Creek, <sup>(2)</sup> Kamloops Lake, stibnite is found in a cinnabar deposit which occurs in Tertiary volcanic rocks. The cinnabar is either disseminated through the rock or is concentrated in irregular veins of quartz and calcite. Narrow seams of molybdenite and a little <sup>stibnite</sup> occur in some parts of the deposit.

#### Bridge River Map Area.

So far as known the antimony deposits of the Bridge River Map Area <sup>(3)</sup> are found only in the Cache Creek Series and are confined to a narrow belt along the western limb of the Bridge River anticline. They are closely related to the intrusion of dioritic porphyry dykes and occur in shear zones which either border or are in these dykes. The porphyry in contact with

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- (1) M.F. Bancroft, G.S.C.S 1917 B. p.40.
  - (2) Min. & Met. Industries of Canada, 1907-1908. p.95.
  - (3) A.M. Bateman G.S.C. S 1912, p.208.  
 C.W. Drysdale G.S.C. S 1915, p. 84.  
 W.S. McCann G.S.C. M.130. 1922. p.73.



the deposits is altered to calcite, sericite and halloysite.

The ore consists of irregular shaped lenses of massive, coarsely columnar stibnite in a quartz gangue. Generally stibnite is the only mineral present but sometimes galena and zinc blende are found in association with it. The ore deposition was contemporaneous with or slightly later than the intrusion of the diorite porphyry dykes. These dykes are post Lower Cretaceous in age and are tentatively placed in the Oligocene period.

F.W.Clarke<sup>(1)</sup> says that "high temperatures, the chemical activity of water and mechanical stresses all work together to bring about the formation of sericite." Since the sericite occurs only in contact with the ore deposits these must have been deposited at high temperatures. There is the possibility that the sericitization occurred before the deposition of ore, but the time interval, if any, was very short, as stated in the preceding paragraph.

#### Chilco & Tatlayoko Lakes.

A few small seams of stibnite in association with granitic dykes occur on the west side of Chilco Lake<sup>(2)</sup> about five miles south of Nemiah Valley.

Antimony occurs in the steeply dipping and highly metamorphosed Triassic sediments at the south end of Tatlayoko Lake.<sup>(3)</sup> There are two veins varying in width from a few inches to 4 feet or more. The upper vein strikes S 10 W, and dips

(1) F.W.Clarke U.S.G.S. Bull. 695, 1920, p.596.  
 (2) A.M.Bateman, G.S.C. S. 1912, p.186.  
 (3) Examined by the writer.

N.E., while the lower vein strikes approximately N 40 W, and has a varying dip to the N.E. The vein filling consists chiefly of quartz and auriferous stibnite and in places a few scattered fragments of the wall rock. In one instance coarse crystal terminations of quartz were found. On close examination of the gangue it is seen that the quartz is frequently crystallized in elongated crystals approximately at right angles to the vein wall. These facts associated with a noticeable banding of the veins, strongly suggest deposition in open fissures. The wall rock, adjacent to the vein, has been altered to a soft yellowish green rock through which fine crystals of pyrite and arsenopyrite are disseminated. The banding is due to the distribution of the metallic minerals pyrite, arsenopyrite, sphalerite and stibnite through the quartz gangue. The pyrite, sphalerite and arsenopyrite are found chiefly along the walls of the vein, but where the vein is narrow the arsenopyrite may extend as fine acicular crystals from wall to wall. The stibnite occurs in the inter-crystal spaces of the quartz and as segregated masses near the centre of the vein. There is some disseminated ore in which the minerals are more or less evenly spaced, but slight banding is also noticeable. The stibnite is either massive, or is found in radiating masses of coarsely bladed crystals. While some occurs disseminated through the quartz, the major part is found in veins of almost pure sulphide, which vary in width from 2 or 3 inches to 1½ feet or more.

The deposit is genetically associated with the intrusion of a monzonite stock in the close vicinity. The presence

of arsenopyrite and the association of evidence indicates deposition at intermediate or relatively high temperatures.

#### Portland Canal District.

Stibnite is reported in one or two instances in the Portland Canal District. In one deposit it is associated with tetrahedrite, galena and chalcopyrite.

#### Skeena River District.

The Skeena River District is underlain by the Hazelton Group, the Skeena coal bearing series and the Buckley Eruptives. These latter rocks intrude the two former series. "The intrusive granitic masses of the Buckley Eruptives have everywhere played an important part in the deposition of ore bodies."<sup>(1)</sup> These eruptive rocks are provisionally placed in the Tertiary but may be older, but they cannot be older than Lower Cretaceous as the Skeena Series of that age is cut by them.

The stibnite occurs 5 miles from Hazelton between Sixmile and Fourmile Creeks. "The ore is developed along the contact of the sedimentaries and the granite; the hanging wall is highly metamorphosed sandstone and the footwall is granite. On the foot wall the ore consists of white quartz with small quantities of disseminated galena, while on the hanging wall the mineralization is much heavier, there being 18 inches to 2 feet of almost solid sulphides of antimony, lead, arsenic, silver and copper and a little white quartz gangue; there is also a little free sulphur."

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(1) W.W.Leach. G.S.C. S 1909. p.64.

Other than stibnite and galena, no definite sulphides are mentioned. This information is too vague to draw any reasonable conclusions as to the temperature of formation of the deposit.

#### Atlin District.

Stibnite occurs 10 miles north of Golden Gate<sup>(1)</sup> Taku Arm, in nearly flat lying, fine textured shales of the Laberg Series (Jura-Cretaceous). The vein varies in width from 3 to 5 feet and is, in general, conformable with the bedding planes of the shales. There are in addition a number of veinlets, within 6 feet of the upper wall of the main vein, which vary in width from a fraction to 2 or 3 inches. The vein material is either quartz or alternating bands of quartz and shales; the latter, at times, occupying as much as one half the vein. The quartz is usually heavily mineralized with stibnite and a little galena.

At the Engineer Mine,<sup>(2)</sup> 10 miles south of Golden Gate, D.D.Cairnes reports native antimony in association with native gold, tellurides, pyrite and limonite in a quartz gangue. No other antimony minerals are mentioned. The deposit is of importance for its gold values.

#### Yukon Territory.

In the Yukon Territory stibnite occurs in the Wheaton River, Whitehorse and Conrad mining districts.

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(1) D.D.Cairnes, G.S.C., M.37, 1913, p.116.

(2) D.D.Cairnes, G.S.C., S 1910, p.37.

The antimony of the Wheaton district occurs in a more or less localised area,  $5\frac{1}{2}$  miles long by  $1\frac{1}{2}$  miles wide, extending from the crest of Chiefton Hill eastward to the eastern limit of Carbon Hill. The greater number of deposits are found on the western slope of Carbon Hill.

The rocks of the district, in which the deposits occur, are the Jurassic Coast Range granodiorite and the overlying late Cretaceous or early Tertiary volcanics consisting of andesitic dykes, stocks, sheets, flows, tuffs and breccias.

The deposits are fissure veins occurring in both the granodiorite and the early Tertiary volcanics; the most persistent fissures being in the granitic rock. They vary from 2 inches to 6 feet, the better deposits averaging 1 to 3 feet in width with very little alteration of the wall rock. The vein filling is mainly quartz with minor amounts of barite and calcite although in places it is chiefly stibnite with which there may be associated minor amounts of sphalerite and jamesonite. The quartz is often massive with no crystal form but it frequently occurs in large crystals pointing toward the centre and forming typical comb structure. The barite and calcite are granular. Layers of gouge from  $1/8$  inch to  $1/4$  inch thick are found on both walls of the vein, but there are no fragments of the wall rock in the vein.

The metallic minerals are stibnite, jamesonite, grey copper, argentiferous galena, sphalerite and arsenopyrite.

(1) D.D.Cairnes, G.S.C. M. 31. p.113.

The stibnite occurs either as columnar radiating crystals or purely granular, with all variations between the two. Sphalerite and jamesonite are commonly associated with the stibnite while the galena is disseminated through the gangue. The grey copper is in scattered grains associated with the stibnite and galena, but some veins consist entirely of quartz, galena and grey copper. The ores high in antimony may be low in silver and visa-versa, but high values of both occur in the same place. Although the silver is more commonly associated with the galena the stibnite is also silver bearing.

The oxidation of the ores is very limited. The oxide minerals are stibiconite, lead carbonate and malachite. There is little or no secondary enrichment.

The presence of comb quartz in the centre of some veins indicates that deposition may have taken place in open fissures but at intermediate temperatures, as shown by the associated minerals.

(1) In his report on the same district in 1915, D.D.Cairnes says "The veins all occupy fissures in the containing rocks which are for the most part the Coast Range granitic intrusives. Occasional veins, however, are found in the Mesozoic andesitic rocks which are older than the Coast Range intrusives." The rest of this report agrees with his previous work, but in this he appears to differ.

Whitehorse District.

(1) D.D.Cairnes, GSC. S 1915, p.46.

(1)

The Whitehorse Copper Belt is characterized by contact metamorphic deposits in limestone at and near the contact of a granite intrusive. The deposits are found in both the limestone and the granite, which has been highly altered in these deposits. The constituent minerals are typical of contact deposits; the more common are; magnetite, hematite, bornite, chalcopyrite, garnet, epidote, augite, scapolite, tremolite, actinolite, quartz and calcite. The less common metallic minerals are tetrahedrite, chalcocite, molybdenite, arsenopyrite, galena, stibnite, pyrrhotite, pyrite, zinc blende and rarely free gold.

#### Conrad District.

(2)

The ores of Windy Arm occur in the Windy Arm Series consisting of volcanic rocks, both intrusive and extrusive which out and lie upon the Coast Range Batholith of Jurassic age. The ores occur in true fissure veins filled with quartz. The stibnite is associated with arsenopyrite and pyrite. Jamesonite is found in association with galena, arsenopyrite, chalcopyrite and pyrite.

#### 6. Rocks with which Antimony Ores are Associated.

##### (a) Igneous.

Antimony ores are commonly associated with igneous rocks of intermediate acidity such as diorites, quartz diorites, monzonites and quartz monzonites; they are also genetically related to granites. These rocks may be either plutonic, hypabyssal or extrusive. The mineral deposition may occur either

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(1) R.G. McConnell. G.S.C. 1050, 1909, p.20-32.

(2) D.D. Cairnes. G.S.C. S - 1908.

in the igneous rock itself, along its intrusive contacts, or within the intruded rocks at varying distances from the igneous contact.

(b) Effect of Wall Rock on Deposition.

The chemical composition of the wall rock has little or no effect upon the deposition of antimony ores, but their physical properties influence the structure of the veins. The exceptions are the metasomatic replacement deposits in limestone.

7. Classification of Antimony Deposits.

(a) Geological Conditions under which Antimony occurs.

In considering the geological conditions under which antimony occurs, it should be kept in mind that the association of minerals found in any vein, may not be of contemporaneous deposition, but may represent a sequence in deposition or even distinct epochs of mineralization. Such sequences and breaks in mineralization might result in marked differences of temperature at which the various minerals were deposited. Thus stibnite might be associated with typical high temperature minerals, yet it may have been deposited under intermediate or even low temperature conditions and visa versa.

In many of the reports contained in this thesis no mention was made of any sequence or break in the mineralization so that any classification of antimony deposits, based on these reports, must be accepted with the reservation that the mineral association, found in the deposits, has been formed contempora-



neously or if a sequence or break in mineralization occurred, it was of such a character as not to alter the conditions of temperature to any large degree.

In discussing the temperatures of deposition the conditions of pressure, existing at such a time, must also be considered. Pressure is of importance only when the mineral solutions contain volatile constituents or gases which render them the natural solvents of any contained minerals. In this case a slight decrease in pressure might be of vital importance in allowing such constituents to escape which would result in the deposition of the otherwise soluble minerals. Pressure is naturally of great importance in veins formed above  $365^{\circ}\text{C}$  as this is the critical temperature of water, but relatively few antimony deposits are formed at such temperatures. The natural solvent of antimony is an alkaline solution. The above evidence strongly suggests that pressure is of minor importance in the deposition of antimony ores. Such a conclusion is substantiated by the formation of stibnite at Steamboat Springs, Nevada, where this mineral is being deposited in gravels 30 feet below the present surface. Lindgren draws an analogy, in formation, between the Steamboat Spring deposit and that found in a conglomerate in Iron County, Utah. From this it is the writer's opinion that the important factors governing the deposition of antimony minerals are changes in temperature and alkalinity of the solutions carrying the antimony. In this it must not be assumed that the deposition is confined to any one particular zone of temperature, because stibnite and other antimony minerals occur in both contact meta-

morphic and low temperature deposits, but the evidence suggests that the important commercial deposits have been formed at intermediate temperatures or slightly lower.

(b) Proposed Classification.

A. Contact Metamorphic Deposits.

B. High Temperature Vein Deposits.

C. Intermediate Temperature Deposits.

(1) Metasomatic Replacements.

(2) Fissure or Shear Zone Deposits.

D. Low Temperature Deposits.

E. Sulfotarie Deposits.

A. Contact Metamorphic Deposits:

So far as known the contact metamorphic deposits in which antimony minerals occur, are few in number. The only definite occurrence is at Zimapan, Mexico, where jamesonite is found in association with contact metamorphic minerals. In the Whitehorse district, British Columbia, stibnite occurs with contact metamorphic minerals. Other uncertain occurrences are to be found in Sardinia, Alaska, Skeena district, British Columbia, and South Ham, Quebec.

B. High Temperature Deposits.

Few typically high temperature minerals occur in association with antimony minerals. Such minerals as tin, scheelite, pyrrhotite and tourmaline are, however, found in antimony bearing deposits in Mexico, Sardinia, Alaska and the Arabia District, Nevada, respectively. Of these deposits that in Sardinia is the

only one mined for its antimony content. The deposit in the Arabia District, Nevada, consists of highly oxidized argentiferous jamesonite.

#### C. Intermediate Temperature Deposits.

(1)  
Lindgren states that in this type of deposit, "The metals contained are principally gold and silver, often with large amounts of copper, lead and zinc. In the deep-seated deposits molybdenum, bismuth tungsten and arsenic are not uncommon associates; we find the same metals here, though they are much less prominent; in addition there is also much antimony and in places tellurium. The ore minerals are sulphides, arsenides, sulphantimonides and sulpharsenides. Pyrite, chalcopyrite, arsenopyrite, galena, zinc blende, tetrahedrite, tennantite and native gold are the most common and on the whole there is not much variety and complexity. ... The metallic minerals develop both in the filling and in the altered country rock, but in the fissure veins proper it is common to find the valuable ores mainly in the filled spaces. The dominating gangue mineral is quartz, but carbonates are also common, such as calcite, dolomite, and ankerite, more rarely siderite; fluorite and barite are occasionally of importance, chalcedony and opal are rarely found."

It is the writer's belief that a large majority of the deposits described in the foregoing pages would come under this classification.

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(1) Lindgren - Mineral Deposits. 1919. p.547.

#### D. Low Temperature Deposits.

Deposits of this type are somewhat common and are often associated with cinnabar, this latter mineral being of more importance than the antimony compounds. Such deposits are found in Germany, France, Mexico, United States and Alaska.

#### E. Sulfotario Deposits.

An example of this type of deposit is given in Pereta, south Tuscany.

Attention should be called to the formation of stibnite at Steamboat Springs. Here this mineral is forming from hot spring waters which permeate gravels 30 feet below the surface. It is in a class by itself and might be classified under "Deposits formed from Hot Spring Waters, at or near the surface." An analogy between this deposit and one in Iron County, Utah, is drawn by Lindgren.

Stibnite is also found in placers in Alaska and New Zealand. It accompanies typical placer minerals as garnet, magnetite, gold, etc., but such placers are formed at short distances from the source of the stibnite.

#### 8. Age of Antimony Deposits.

Antimony deposits have been formed during many periods throughout geological time. Most of the deposits bordering the Atlantic appear to have developed prior to the Carboniferous period. Important exceptions are deposits in Tuscany which are associated with Quaternary volcanism. The antimony deposits bordering the Pacific ocean have a large range in geological time, but a great many have been formed since Cretaceous

time. The antimony deposits of Alaska, British Columbia and Nevada are mainly of Tertiary age. Deposits of similar age occur in New Zealand. This Tertiary antimony mineralization is mainly connected with vulcanism and deposition has occurred at varying depths but at temperatures ranging from high temperatures to sulfotario deposition.

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