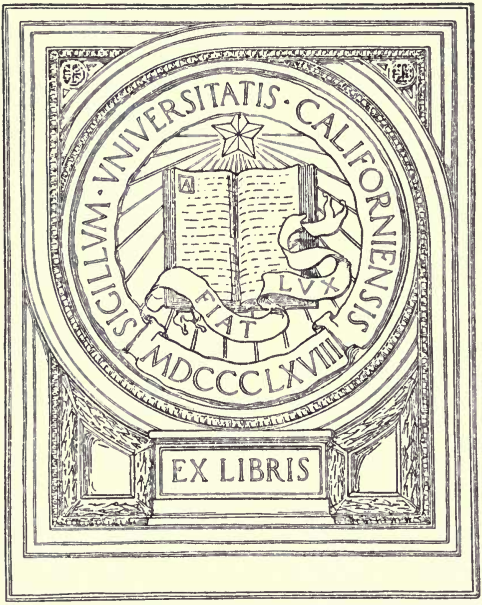

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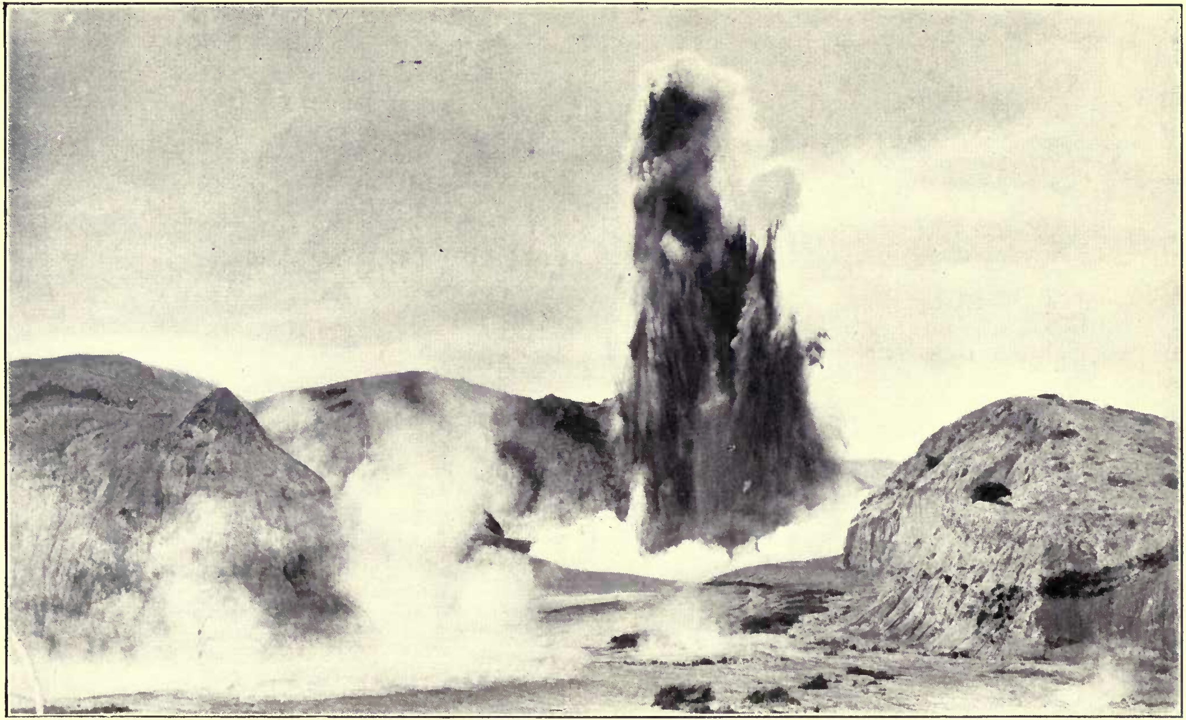

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WAIMANGU GEYSER, ROTORUA, NEW ZEALAND.

A TEXT-BOOK OF
MINING GEOLOGY

FOR THE USE OF MINING STUDENTS
AND MINERS.

BY

JAMES PARK,

PROFESSOR OF MINING AND MINING GEOLOGY;
DIRECTOR OF OTAGO UNIVERSITY SCHOOL OF MINES;
MEMBER OF THE INSTITUTION OF MINING AND METALLURGY;
MEMBER OF THE AMERICAN INSTITUTE OF MINING ENGINEERS
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INSTITUTE OF MINING ENGINEERS.

With 78 Illustrations and 3 Plates.

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1906.

PREFACE.

It is only in recent years that Mining Geology has been regarded as of sufficient importance to warrant its elevation to the dignity of a distinct department in the Mining Schools and Colleges of English-speaking communities. For long enough it was treated as a subordinate subject, being taught for the most part as an introduction to the principles of mining, at a time in his academic career when the young undergraduate, possessing no personal experience of ore-bodies as they occur in Nature, was least able to grasp the true bearing of the subject in its relation to the economics of the mining industry. In the mining academies of Continental Europe, economic geology has always occupied a prominent and respected place.

The matter in the following pages comprises a series of lectures issued in Bulletin form at the end of 1902. The exhaustion of that little publication has encouraged the author to present the same matter in this revised and enlarged form.

The new chapters on "Ores and Minerals Considered Economically," "Mine-Sampling and Ore-Valuation," and "The Examination and Valuation of Mines" have been added to comply with the requirements of the new curriculum for the associate-diplomas in Mining, Metallurgy, and Geology.

The genesis of ore-deposits is a subject surrounded by many perplexing problems. The chief difficulty encountered by the teacher is that the generalisations have not yet been crystallised in forms sufficiently definite to be universally accepted as first principles.

The publication of the late Professor Posepny's classic paper on *The Genesis of Ore-Deposits* in 1888 may be said to have marked the beginning of a new era in the history of economic geology. Since that date the literature of the subject has been enriched by the writings of Vogt, Stelzner, Beck, de Launay, Van Hise, Rickard, Becker, Emmons, Gregory, Kemp, Chamberlain, Lindgren, Weed, Spurr, Sir C. Le Neve Foster, S. Herbert Cox, Grenville Cole, and other distinguished geologists.

The American School has not endorsed the extreme views of Posepny, or the fascinating theories of Sandberger, but gradually developed a conception lying somewhere between the two, with a distinct leaning towards the teachings of the former.

With respect to Mine Sampling and Valuation, it is manifest that no hard and fast rules can be laid down. Of American, English, and German mining engineers with whom the author has been associated in mine examination, it is noteworthy that all were agreed as to the prime essentials, although differing within certain small limits in matters of procedure and routine. Differences in minor details must always exist where men vary in experience and temperament.

Students reading for advanced work and honours will find a fertile field of reference in such excellent works as *The Genesis of Ore-Deposits*, published by the American Institute of Mining Engineers; the treatises on Ore-Deposits by Stelzner, Beck, Phillips, and Louis; *The Sampling and Valuation of Mines*, by Rickard; the splendid Memoirs and Reports of the Geological Survey of the United States; and the valuable papers scattered through the Transactions of the American Institute of Mining Engineers, of the Institution of Mining Engineers, of the Institution of Mining and Metallurgy, and of the New Zealand Institute of Mining Engineers. The acknowledgments of the author are due to the writers of these papers and to friends in many places for much valuable assistance in the preparation of these pages.

THE AUTHOR.

UNIVERSITY, DUNEDIN, N.Z.,
March 1906.

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MINING GEOLOGY.

CHAPTER I.

INTRODUCTORY.

CONTENTS:—The Scope and Purpose of Geology—Geological Structure of the Earth—Beginning of Geological Time—The Action of Water in Destroying and Re-forming—The Earth's Crust mostly Sedimentary—The Alteration of Sedimentaries—Fossil Contents—Geological Time marked by Distinctive Life—Origin of Igneous Rocks—Overflow Rocks—Dyke Rocks—Plutonic Bosses—Alteration of Igneous Rocks—Metals and Minerals in Igneous Rocks—The Influence of Dykes—Classification of Igneous Rocks—Importance of Petrography.

The Scope and Purpose of Geology.—The study of geology is undertaken by two classes of student. There is the patient investigator who, in the interests of pure science, without hope of material gain, is content not only to know that a rock is composed of mineral matter, but extends his researches to the investigation of the origin, composition, and structure of the rock. Then there is the utilitarian, who views a mineral from a commercial standpoint, and is willing to undergo a special course of training in order to be able to distinguish the valuable from the base and worthless.

The science may therefore be divided into Theoretical Geology, which investigates the origin and structure of the rocky crust of the earth; and Economic or Mining Geology, which bears more directly on mining, and the development of the mineral industry. A knowledge of the fundamental principles of the first is necessary to understand the second, and for this reason every mining student should prepare himself for his profession by going through a systematic course in General Geology.

It is satisfactory to observe that many of the most eminent mining engineers in Europe, America, and Australia are distinguished geologists. What anatomy is to the modern surgeon, so is geology to the mining profession.

Geological Structure of the Earth.—The crust of the earth is the great repository of minerals and metals, and therefore a brief consideration of its origin and structure will afford a better understanding of the manner in which ore-bodies and mineral-deposits occur.

Beginning of Geological Time.—Geological time dates back to the first beginning of the physical conditions which now prevail upon the earth. To make this clear, it will be necessary to trace the evolution of the earth to its present form.

According to astronomers and physicists, the earth, like many celestial bodies at the present time, once existed as a nebular mass of glowing incandescent gases swinging through space. By the radiation of its heat, this globe, in the course of countless ages, became sufficiently cool for a thin skin or crust to form on the outer surface. By the continued radiation of the heat, the crust became thicker and thicker, and, in attempting to adapt itself to the smaller dimensions of the molten mass below, became crumpled and rucked up into ridges and valleys, like the skin of a dried-up apple.

In the course of time the scarred and gnarled igneous crust became cool enough to permit the condensation of the watery vapours which enveloped the earth. The waters settled in the hollows, and formed the first seas that ever existed on the face of the globe.

The restless waters of the new-born seas at once began to wear away the dry land, and the streams draining the valleys to deepen and widen their channels. The denuded material was spread out in layers and beds on the rocky floor of the seas, thus marking the beginning of the conditions of sedimentation that have existed without interruption up to the present day. These ancient freshwater sediments were the first records of geological time.

The Action of Water in Destroying and Re-forming.—From that date up till now, water has continued to be the most powerful agency in sculpturing and modifying the surface of the earth. In wasting and eroding the dry land, in transporting the eroded material, in sorting and spreading it out, the action of water has been unceasing throughout all time.

No portion of the original igneous crust, or even of the first-formed sediments, has ever been found; but shreds and patches may still exist, buried beneath the deposits of later times.

The amount of matter forming the earth is practically a fixed quantity; hence it is evident that all the deposits and beds now forming the surface of the earth must have been derived from the destruction of the first igneous crust, or of sedimentary rocks of later date.

Ever since the beginning of geological time the dry land has been denuded by water, yielding the material to form new deposits in seas and lakes. Through the continual crumpling of the crust of the earth, these deposits in course of time became dry land, and, in their turn, were subjected to the agents of erosion, again yielding material to form still newer deposits or strata. This action is still going on, the older formations providing the material for the younger.

The same material has appeared re-sorted in different forms, in different geological ages. It is now easy to understand how some of the older formations have been entirely removed by this everlasting denudation, or are represented only by isolated remnants of small extent.

The Earth's Crust mostly Sedimentary.—An examination of the crust of the earth shows that it is composed principally of stratified rocks—that is, rocks occurring in parallel beds or layers. A study of the materials forming these rocks, and of their fossil contents, shows us that they have been formed by the gradual deposit of sediments on the floor of some sea or lake, in some cases by precipitation from solutions, or by the growth and accumulation of animal or vegetable organisms.

The physical structure of sedimentary or clastic rocks—as they are sometimes called—is dependent on three main factors, namely, the texture of the material, the character of the cementing medium, and the amount of induration, alteration, or metamorphism to which the material has been subjected.

Water has possessed through all time the same eroding, transporting, and sorting power, and what we now see going on in our valleys and on our shores is a fair example of what took place in earliest geological time.

The gravels on the shores formed conglomerates; the waterborne sands formed sandstones; the more distant muds became shales; while the littoral shell-beds and coral reefs became limestones.

The Alteration of Sedimentaries.—The older sedimentaries have been subject to all the later movements which have affected the crust of the earth. They have been indurated by the great weight of superincumbent strata, plicated and contorted by entanglement in great earth-folds, and altered by the simultaneous action of pressure, heat, and circulating thermal waters. Thus limestones have been changed to marbles, sandstones to quartzite, mudstones and shales to slates or schist.

Fossil Contents.—Examination has shown that the earlier existing strata contain a few indistinct and badly preserved remains of plants and animals of a very primitive and lowly type.

Beds higher in the succession are found to contain a large and varied assemblage of plant and animal remains, many of a highly complex structure, such as molluscs, fishes, huge bird-like lizards, saurians, palms, and tree-ferns. The higher or younger deposits contain, besides molluscs and fishes, the remains of many mammals which have representatives living at the present time. In other words, there has been a gradual succession of life in time from the lowly to the more highly organised forms.

Geological Time marked by Distinctive Life.—Exhaustive investigation has shown that certain organic forms occur only in certain beds. Such fossils are termed characteristic or distinctive forms. Geologists have taken advantage of these to divide geological time into periods, just as historic time is divided into periods by succeeding dynasties or empires. These periods are purely empirical, and are used for convenience of description and study.

Geological time embraces three great periods, which are further subdivided as shown below :—

TERTIARY, or Cainozoic	Recent. Pleistocene. Pliocene. Miocene. Eocene.
SECONDARY, or Mesozoic	Cretaceous. Jurassic. Triassic.
PRIMARY, or Palæozoic	Permian. Carboniferous. Devonian. Silurian. Cambrian. Laurentian.

Such terms as Permian, Devonian, etc., are time names, and cover vast æons. When a rock is said to be of Miocene age, a reference to the table will show that it is comparatively young; whereas a rock of Silurian age is one of extreme antiquity. For purposes of close investigation, these time periods are sometimes still further subdivided by geologists.

Origin of Igneous Rocks.—Throughout all time the outer shell or crust of the earth has been subject to the intrusion and overflow of molten magmas from below; and there is abundant evidence that these igneous intrusions or outbursts were more frequent, more violent, and more widespread in earlier than in later geological times. Yet, notwithstanding the frequency of volcanic outbursts, the fact remains that probably nine-tenths of the rocks forming the crust of the earth are of sedimentary or aqueous origin.

Although subordinate in extent and mass, the eruptive rocks play an important part in the distribution and occurrence of ore-bodies and mineral deposits. Not only are they metalliferous themselves, but in many cases their intrusion has caused a fracturing of the rocks, which they penetrated, thereby forming fissures which have subsequently been filled with mineral matter.

Overflow Rocks.—An igneous magma, which issues from a crack or vent and overflows the surrounding country, is called a volcanic rock or lava. Such overflow magmas, if they cool rapidly, are glassy in structure; or, if they cool less rapidly, consist of a glassy base, in which there develops a number of minerals, either as grains or crystals.

Dyke Rocks.—The portions of the magma which cool in cracks and vents are termed dykes. In the majority of cases, the existence of dykes is only revealed by the denudation of the surrounding country.

Dykes necessarily cooled slowly, and under great pressure, the latter being due to (*a*) the weight of the surrounding and overlying rocks; (*b*) the internal stress of the included gases and steam; and (*c*) the stress due to the molecular movement of the constituents during the process of cooling; and (*d*) gravitational stress.

Magmas which cool slowly, under pressure, in most cases assume a crystalline structure.

Plutonic Bosses.—Magmas projected from below into the adjoining rocks, in the form of huge, dome-shaped masses, which did not reach the surface, but were subsequently exposed at the present surface by denudation, are termed "bosses." Granite, for example, often occurs in the form of bosses.

These bosses are generally believed to occupy deep-seated cavities in the crust, and hence their appearance at the surface is held to indicate a land surface long subjected to erosion. They are completely crystalline in structure, even more entirely so than dyke rocks.

Thus we see that, according to the varying conditions of eruption, cooling, and pressure, the same magma may become a volcanic glass, an ordinary lava, a dyke rock, or a highly crystalline boss. The difference is one of physical constitution rather than chemical composition.

Alteration of Igneous Rocks.—All igneous rocks, like sedimentaries, are subject to alteration. Pressure in the presence of superheated steam has often caused a rearrangement of the constituents; while the circulation of thermal waters has led to the elimination of some, and the substitution of other, constituents of secondary origin. Moreover, it is found that intense metamorphism may cause altered lavas and tuffs to assume a schistose structure not unlike that induced in altered sedimentaries.

Metals and Minerals in Igneous Rocks.—No volcanic rock of recent date is known to contain metalliferous deposits of commercial value. Traces of gold, silver, and most of the base metals have been found in modern lavas; but the only minerals of economic importance associated with these rocks are sulphur and gypsum, both of secondary origin.

The Miocene andesitic lavas and tuffs of the Sierra Nevada and Cripple Creek districts in America; Transylvania and Banat in Hungary; of Borneo and Sumatra in Malaysia; and of Hauraki Peninsula in New Zealand, contain gold- and silver-bearing veins of great value, in which ores of copper, lead, and zinc are sometimes present.

A flow of andesite near the Manukau Heads in New Zealand contains large grains of native copper, an occurrence which is rare and therefore of great scientific interest.

Volcanic tuffs and lavas are also the matrix of diamonds, opals, and other precious stones.

The Influence of Dykes.—Dyke rocks are not often themselves metalliferous; but they have exercised a potent influence on the distribution of metalliferous deposits. Many valuable veins of gold and copper occur in the vicinity of dykes; and although there is little definite knowledge concerning the origin of vein-matter, it seems fair to assume that the intrusion of the dyke-material originated fractures and fissures in the adjacent country, which then became channels or tracks for the circulation of mineral-laden waters.

Intrusive bosses, such as those of granite, are often impregnated with tin-stone near the contact with sedimentary strata; and in other cases the sedimentary rocks, in the neighbourhood of the granite, are traversed by valuable veins of tin and copper.

The association of tin veins and granite bosses is too frequent to be a mere coincidence; and we are compelled to conclude that, in some way which is not very clear to us, the vein and its contents are connected with the presence of the boss.

The intrusion of the boss may possibly have tilted and fractured the surrounding rocks; or the boss may have been the anvil against which the softer and more yielding sedimentaries were crushed and fractured by the lateral stresses initiated by the secular folding of the crust of the earth. Igneous magmas are charged with water and gases. During the process of cooling, most of the water and gases are expelled as highly heated steam, and, as will be shown later on, there is much evidence to support the belief that the steam and gases were laden with dissolved metals, which were afterwards deposited in the zone of fracture.

Classification of Igneous Rocks.—For our present purposes, igneous rocks may be classified in three principal and easily distinguishable groups as follows:—

Class.	Volcanic Type.	Altered or Holocrystalline Type.
A. Basic, . .	Basalt.	Diabase.
B. Intermediate, .	Andesite.	Diorite.
C. Acidic, . .	(*a*) Trachyte. (*b*) Rhyolite.	Syenite. Granite.

The types which have proved the most productive are diabase, diorite, andesite, and granite.

Importance of Petrography.—Petrography was formerly a narrow branch of general geology. Of late years it has developed into a distinct science, which concerns itself chiefly with the minute structure, composition, and nomenclature of igneous and crystalline rocks, and although the generalisations of petrography have little bearing upon the phenomena of structural geology, it is needful that every geologist should have an intimate knowledge of its leading features.

Valuable minerals are so frequently associated with igneous rocks that it seems impossible to avoid the conclusion that a close genetic relationship exists between them. What this relationship really is has yet to be determined in the majority of ore-deposits.

Rock-forming constituents are now known to separate in the cooling magma in a definite order, and the investigation of the laws governing magmatic differentiation promises to throw much light on the genesis of ore-deposits.

CHAPTER II.

CLASSIFICATION OF MINERAL DEPOSITS.

Contents:—The Basis of Classification—Morphological Classification—Superficial Deposits—Gold Placers—River Placers—Lacustrine Placers—Black Sand Beaches—Deep Leads of Victoria—Cement Placers—Dry-blowing Placers—Forms of Alluvial Gold—Associates of Alluvial Gold—Origin of Alluvial Gold—Stream Tin—Origin of Stream Tin—Platinum Placers—Platinum in Russia and America—Iron Sand Placers—Gem Placers, Diamond, Ruby, Sapphire—Massive Deposits—Bog Iron—Action of Descending Waters—Salt—Borax—Gypsum—Sulphur—Stratified Deposits—Strike and Dip of Beds—Inclination of Beds—Thickness of Beds—Examples of Bedded Deposits—Coal—Origin and Formation—Mode of Occurrence—Age—Inclined Position—Faulting—Extent of Faults—Intrusive Dykes and their Effects—Irregularities—Bending of Seams—Varieties of Coal—Rand Banket Reefs—Mansfeld Copper Shales—Silver Sandstones of Utah—Lead Sandstone of Prussia—Copper Conglomerates of Lake Superior—Coprolite Beds—Gypsum Beds—Unstratified Deposits—Deposits of Volcanic Origin—Stockwork Deposits—Contact and Replacement Deposits—Fahlbands—Impregnations—Segregated Veins—Gash Veins—True Fissure Veins.

The Basis of Classification.—Mineral deposits are found in so many different forms, and under so many varying conditions, that the attempts of different writers to formulate a classification, founded upon a natural basis, have not been attended with much success. In any case, it must be remembered that a classification is only an empirical arrangement intended to facilitate the study and investigation of mineral deposits.

The majority of the classifications hitherto proposed are based upon either (*a*) *morphological*, or (*b*) *genetic* considerations, or (*c*) a combination of the two.

The first principles of ore-deposition are still imperfectly understood. The most diverse theories are still advanced by eminent authorities; and it is doubtful if a theory has yet been formulated that will satisfy all the conditions and explain all the facts.

The basis for a natural classification has still to be discovered. Until then, outward form and mode of occurrence seem to offer the most convenient starting-point for the elementary investigation.

The more advanced study, that is, the philosophical inquiry, as to the origin, persistence, and probable value of ore-deposits can only be pursued when some knowledge has been acquired of the fundamental laws of ore-formation. In this case the investigation must be pursued from the genetic standpoint.

We will first deal with mineral deposits from the morphological and afterwards from the genetic standpoint.

MORPHOLOGICAL CLASSIFICATION.

A simple classification of veins and mineral deposits, based upon outward form and mode of occurrence, but entirely independent of age or mineral character, is as follows :—

Class I.—Superficial.
Class II.—Stratified.
Class III.—Unstratified.

For descriptive purposes, these classes may be subdivided into groups or sub-classes, as under :—

I.—Superficial Deposits.

(*a*) *Fragmentary*—Forming alluvial drifts.
(*b*) *Massive*—Forming layers and sheets.

II.—Stratified Deposits.

(*a*) *Constituting beds*—Forming members of a stratified formation.

(*b*) *Disseminated through a bed.*

III.—Unstratified Deposits.

(*a*) *Deposits of volcanic origin.*
(*b*) *Stockwork deposits.*
(*c*) *Contact and replacement deposits.*
(*d*) *Fahlbands.*
(*e*) *Impregnations.*
(*f*) *Segregated veins.*
(*g*) *Gash veins.*
(*h*) *True fissure veins.*

Class I.

SUPERFICIAL DEPOSITS.

(*a*) *Fragmentary.*

Definition of Placer Deposits.—These embrace alluvial deposits of all kinds, whether beach sands, river gravels, lake deposits, or glacier drifts containing loose particles of gold, tin-ore, platinum, iron ores, or precious stones. They also include the alluvial deep leads, or deep placers, of California, Victoria, and New South Wales, which are often covered with a sheet, or sheets of basalt.

Gold Placers.

That portion of the drift in which the gold is concentrated is termed *pay-wash*, *pay-dirt*, or *pay-streak*. When the pay-wash is covered by a considerable depth of gravel-drift or other cover, it is termed a deep-lead.

Methods of working Placers.—Alluvial drifts, according to their situation, are worked as follows:—

(1) By ground or gravitation sluicing with water not under pressure.

(2) By hydraulicking—that is, ground sluicing with water under pressure.

(3) By hydraulicking and elevating with water under pressure. This method is only resorted to when the configuration of the ground renders it impossible, or too costly, to construct a tail-race for gravitation sluicing. It is worked with much success at the Blue Spur and other claims in New Zealand.

(4) By bucket and suction dredges, when the material is mainly or partly below water-level, as, for example, on sea-beaches, maritime lagoons, lakes, river-beds, and river-flats.

Examples of Gold Placers.—Familiar examples of gold-bearing gravels are the alluvial drifts of Victoria, West Australia, Klondyke, California, New Zealand, and Altai Mountains, in Central Siberia.

Gold-bearing beach-sands containing ironsand, mostly magnetite, occur along the shores of Westland and Southland, in New Zealand, and the Gold Coast of West Africa.

Among later alluvial gold discoveries, that at Cape Nome, in Alaska, is the most important. A sloping plane or tundra extends from the sea back to the foot of the mountains. It consists of a succession of beds of sand, gravel, and clay resting on the upturned edges of the Palæozoic basement rock. The surface is covered with a layer of tundra moss and decaying vegetable peaty matter to a depth of 18 inches or 24 inches. The gold-bearing matter is found along the beach, being apparently a rewash or concentrate of the tundra gravels and sand.

The tundra gravels bear no evidence of glacier origin, but appear from their bedded and water-worn character to have been deposited in a lake-basin or in a shallow sea near the estuary of a large river.

Glacier Drifts.—Country that was once overrun by glaciers is found to contain two classes of transported matter—one transported by ice, the other by water. The first forms tumbled morainic masses, the latter water-worn gravels and sands deposited by the river which drained the bottom of the glacier. Both classes are often mixed at certain points. When the country is gold-bearing, the glacier gravels and morainic matter contain gold. The moraines are formed by ice which cannot separate the gold from the rock debris; hence the gold is scattered through it just as the glacier happened to drop it. The glacier gravels, on the

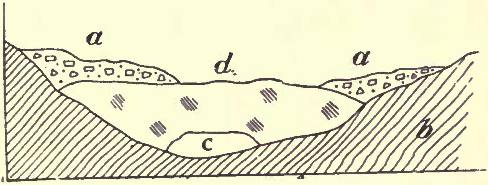

FIG. 1.—Section of Glacier above Terminal Face.

(*a*) Moraines. (*c*) Glacier tunnel.
(*b*) Basement rock. (*d*) Glacier ice.

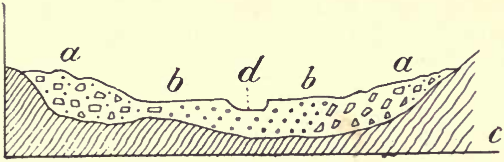

FIG. 2.—Section of Glacier Valley.

(*a*) Glacier moraines. (*c*) Basement rock.
(*b*) Glacier gravels. (*d*) Glacier river.

other hand, being largely a rewash of the moraines, contain the gold in a more concentrated form.

Many of the gold-bearing terraces in New Zealand and in the higher valleys of the Rocky Mountains bear evidence of glacier-river origin, while some are composed of a rewash of glacier gravels and morainic matter.

Position of Pay-Wash.—Experience has shown that alluvial gold is deposited along the inner side of the curves in the course of the river. Any stratum of good gravel in the opposite bank was evidently laid down at some previous time, under similar conditions. The accompanying diagram (fig. 3) shows the distribution of the pay-wash. The gold is coarsest at the head of the bar, gradually becoming finer and scarcer, and spreading out below, until the dirt is too poor to pay. So long as the river retains its course, the pay-streak will continue to form as the bar is extended from year to year.

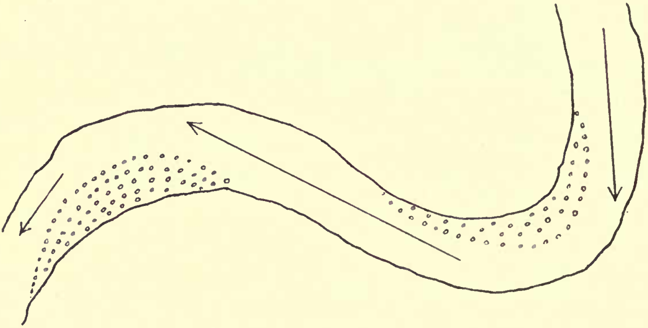

FIG. 3.—Plan of River-course, showing position of gravels.

The average uniform size of the gravel seems to show that the gold is only deposited where the current has a certain medium velocity. At the points where the bends in the river are made more permanent by rocky banks, the pay-gravel is generally deeper and of greater extent than elsewhere.

The richest gold does not collect in the deep pot-holes in the river, as might naturally be expected, but on the bars or rocky ledges below. The reason for this may be that pot-holes generally occur in narrow, rock-bound parts where the velocity and scour of the water are too great to permit the permanent lodgment of the gold particles.

Position of Gold in Drifts.—In alluvial deposits the gold is found in a layer of pay-wash resting either on the *slate* or *schist bottom*, or on a *false-bottom.* In river and creek workings, the pay-wash lies invariably on the slate bottom; but in the alluvia of old lake basins it frequently rests on a false-bottom of stiff clay or cement. In cases where the drift is of considerable thickness, there often occur two or more streaks of pay-wash resting on successive false-bottoms.

River Placers.—A typical section of the river claims of the Buller River, in New Zealand, is shown in the following diagram.

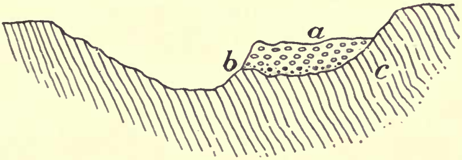

FIG. 4.—Section of Gold-drifts in River Claim.

(*a*) Terrace gravels. (*b*) Pay-wash. (*c*) Slate floor rock.

Old River-Channels.—It sometimes happens that the gold-bearing wash does not occur in the present river-channel, but in an old channel or bed near by. The following figure shows a section of the Manuherikia Valley in Central Otago, New Zealand.[1] The old river-bed was excavated in mica-schist, and the gravels which fill it have been saved from destruction by the rim of schist.

The old river-wash is being worked by ground-sluicing, and the recent gravels in the present river-bed by bucket-dredges.

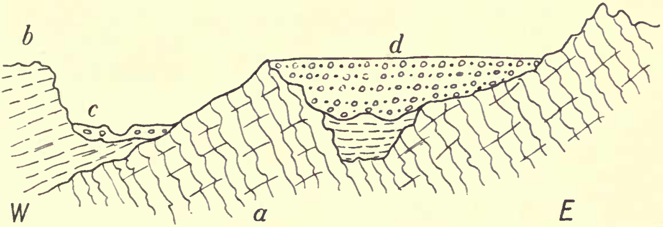

FIG. 5.—Section of Manuherikia Valley, showing old river-channel containing gold-bearing wash. (After Park.)

(*a*) Mica-schist. (*c*) Recent gravels.
(*b*) Pliocene lacustrine beds. (*d*) Older gravels.

Lacustrine Placers.—A typical example of lake beds containing payable pay-wash resting on a false-bottom is shown in the next figure.[2]

Throughout the Manuherikia basin the lacustrine beds have

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[1] J. Park, *Geological Explorations*, 1888–89, p. 24, Wellington, N.Z.
[2] *Loc. cit.*, p. 21.

been tilted almost on edge, thereby greatly increasing the difficulties of working the pay-wash with success.

Black Sand Beaches.—The washing of beach sands is a form of alluvial mining pursued on the sea-beaches of Westland and Southland in New Zealand. The black sand is principally magnetite derived from the disintegration of the neighbouring rocks.

The gold occurs in excessively fine particles, and is found concentrated with the black sand in layers along the sea beach, the laving action of the retreating waves removing the lighter particles of quartz sand.

Deep-Leads of Victoria.—The buried placers of this state are of great extent and value. They may be taken as typical of a class of deposit also found in California. They consist of gold-bearing gravels covered by a single flow of basalt, or by a succession of thin flows separated by beds of gravel.

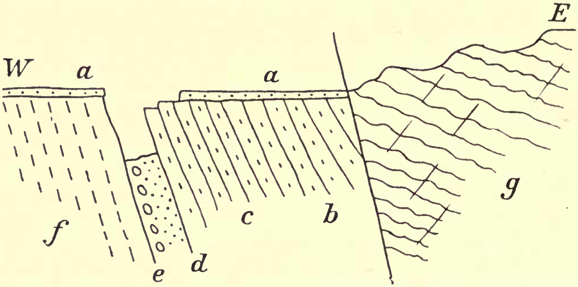

FIG. 6.—Section showing Lacustrine Gold-bearing Wash. (After Park.)

(*a*) Recent gravels.
(*b*) Gray quartz sands.
(*c*) Ferruginous quartz sands.
(*d*) Carbonaceous sands.
(*e*) Gold-bearing wash.
(*f*) Stiff clay.
(*g*) Schist.

The gold-bearing pay-wash lies on the floor of ancient river-valleys into which the lava streams poured from crater-vents and fissures situated in the higher lands. The ancient valleys when comparatively narrow were generally filled with the igneous magma to such a depth as to cause the diversion of the streams into new channels. In some cases the area was invaded by floods of lava which overflowed the district for hundreds of square miles and built up great basaltic plateaux on the sites of the river-valleys and watercourses.

Where the river-valley down which the lava poured was wide, the magma generally spread itself over the gravels in a thin stream. This caused only a temporary or partial diversion of the river, insufficient, it would seem, to compel the river to find a new outlet in another river-system.

Where a succession of gravel beds and basalt flows occurs, it may be inferred that the thin flows only temporarily diverted the river, which maintained its original watershed until the accumulation of material had reached such a height as to completely choke up the old valley, whereby the waters were enabled to command a new outlet through some low saddle or pass into a neighbouring watershed.

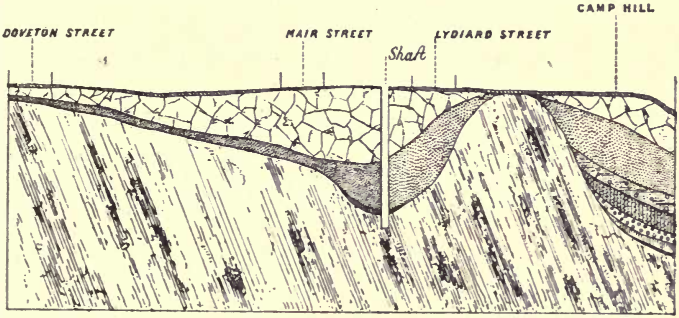

Fig. 7.—Cross-section of Ballaarat Goldfield, showing deep-lead underlying basalt. (After R. Brough Smyth.)

Since the emission of the basalts the country has been dissected by streams and sculptured into the existing ridges, plateaux, and valleys. It is noticeable that the new river-courses are seldom coincident with the old, which still lie buried under their load of gravel and basalt except at the points where their course has been crossed by the newer transverse streams.

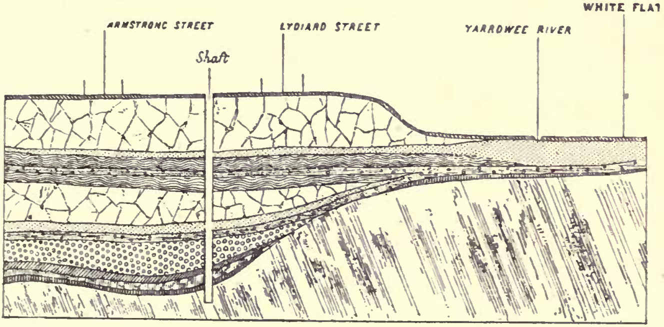

Fig. 8.—Section of Deep-lead Ballaarat Goldfield, showing succession of lava flows and river-gravels. (After R. Brough Smyth.)

This process of denudation has in some cases removed the barriers which bounded the ancient river-valley. Thus the floor of the old valley, with its cap of hard basalt, now forms flat-topped ridges, while the hills which formed the barriers have been worn down into valleys and watercourses.

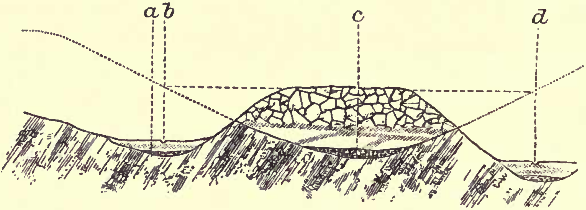

FIG. 9.—Section of Mount Greenock, showing protective effects of basalt cap. (After R. Brough Smyth.)

(*a*) Wash-dirt.
(*b*) Existing watercourse.
(*c*) Wash-dirt underlying basalt.
(*d*) Existing watercourse.

The pay-wash in the deep-leads of Victoria generally lies at the base of the buried gravels resting in a rocky gutter or channel cut in the basement rock.

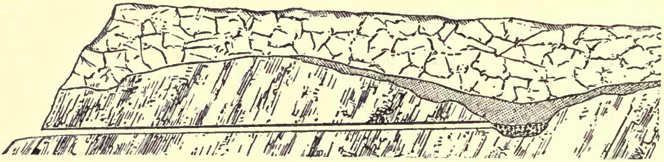

FIG. 10.—Section of Deep-Lead in Daylesford District, showing position of gold-bearing wash. (After R. B. Smyth.)

The deep-leads, according to the contour of the ground, are worked by shafts, or from adit-levels.

Cement Placers.—Gold-bearing gravels have sometimes become consolidated into hard cements, or even conglomerates, by the cementing action of iron peroxide, carbonate of lime, or silica deposited from waters which at one time circulated through them.

Cemented placers are found in all geological formations from the Silurian up to the present day. The most important are of recent and younger Tertiary age.

The quartz grits and conglomerates which form the coal-measures of the Miocene brown coals of New Zealand are gold-bearing throughout Otago, Westland, and Nelson; but only in a few places are they rich enough to be worked for their gold contents.

The importance of these old placers lies mainly in the circumstance that many of the richest placers of a recent or Pleistocene date derived their gold from them by a process of natural concentration.

Cemented gold-bearing gravels, mostly superficial, are common enough in all alluvial fields, and many notable examples are found in California and Central Siberia, more especially in old river-channels.

Gold-bearing cements of a unique kind occur at Kintore, Kanowna, Kalgoorlie, and elsewhere in Western Australia. They differ from the fluviatile water-worn gravels which form the cements in New Zealand and California. According to Rickard,[1] they consist variously of intermingled clays, sands, grits, kaolin, broken rock, iron-stone and quartz, in most cases resting in shallow depressions.[2]

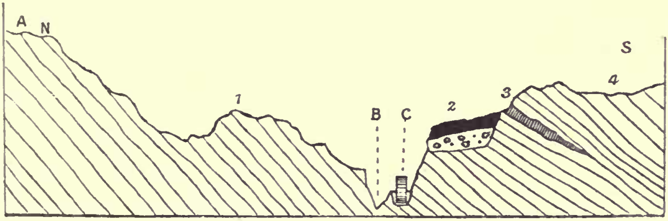

FIG. 11.—Section across Slate River, Collingwood, New Zealand, showing gold-bearing cements below seam of coal. (After Park.)

1. Quartzites.
2. Brown coal lying on gold-bearing cement.
3. Gold-bearing segregated quartz-vein, the source of gold in cements.
4. Quartzites.

Their origin is due to peculiar geological and climatic conditions. The climate is semi-tropical. The surface has been exposed to sub-aerial influences since, probably, the early part of the Secondary period, and is destitute of running streams. The materials are the products of long-continued atmospheric disintegration and erosion. They were transported to their present places by the action of wind, rain, and flood-waters. In no case has the material, or contained gold, travelled far from the parent source. The working of the cements, at Kalgoorlie, led to the discovery of the more valuable lode-formations.

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[1] T. A. Rickard, "The Alluvial Deposits of Western Australia," *Trans. Am. Inst. Min. Eng.*, vol. xxviii.

[2] T. Blatchford, *Bulletin No.* 3, *Geol. Survey of Western Australia.* Perth, 1899.

Dry-blowing Placers.—As a result of the long-continued sub-aerial disintegration, the surface of the flat country around Kalgoorlie has become covered by a deposit of red sandy loam, beneath which there is often blue clay. This material, which occurs most frequently at the head of shallow gullies, is mixed with fragments of iron-stone and a little quartz derived from the gold-bearing lodes in the vicinity.

The gold in this loose surface material is obtained, in the absence of water, by the method peculiar to Australia, known as *dry-blowing*, which consists of screening, shaking, and dry-blowing, (Plate I.).

Forms of Alluvial Gold.—Excepting the larger nuggets, which have been found of all shapes and sizes, up to thousands of ounces, the coarse gold generally assumes a bean-shaped form.

The finer gold occurs as small heavy shots, but more often as thin flakes, ranging from the smallest particle, which almost floats in water, to pieces like bran.

In river claims, where the gold has been derived from the denudation of gold-bearing lodes, fragments of quartz with adhering pieces of the precious metal are often met with.

Associates of Alluvial Gold.—The constant associate of alluvial gold in all countries is magnetite sand, the agencies which led to the concentration of the gold having also collected the more abundant magnetite. It is found that whatever heavy ores or minerals are associated with the gold in the original country-rock are also found with it in the resulting alluvial drifts.

In Collingwood, in New Zealand, considerable quantities of native lead, in the form of round shot, have been found for many years in the sluice-boxes, with the gold. In places it is so abundant as to choke up the ripples. Samples collected by the author, and submitted to chemical examination, disclosed the fact that the lead is almost chemically pure, and sometimes encloses a skeleton of gold.

In Takaka, near Collingwood, the alluvial gold, besides magnetite, is associated with gray-coloured grains of osmium, iridium, and platinum; in Orepuki, with one ounce of platinum for every hundred ounces of gold; on the West Coast and in the fiords with garnets, locally known as rubies; and in Central Otago with large masses of scheelite and magnetite.

Throughout Australia the alluvial gold is often associated with gem sands containing topaz, zircon, spinel, rubies, and garnets.

Origin of Alluvial Gold.—Alluvial gold originated from the weathering and denudation of country containing gold-bearing veins

Photo, W. Eddowes.]

DRY-BLOWING NEAR KALGOORLIE, W. AUSTRALIA.

during countless ages, followed by the concentration of the gold in leads, or channels, by a process of natural sluicing.

Some writers have thought that the occurrence of occasional large nuggets in gravel drifts was an evidence that alluvial gold had been deposited *in situ* from gold-bearing solutions circulating through the gravels, but there is very little evidence to support this contention.

It has been shown, experimentally, by various supporters of this theory, that decomposing organic matter, such as wood, and some base sulphides are capable of causing the precipitation of gold from its solutions. All this is doubtless true, but the difficulties that confront the theory are enormous.

Alluvial gold is found disseminated throughout gravels that are continuous in extent over many square miles, and of great thickness. In many placers the gold occurs in narrow, fairly well-defined leads, on or near an impervious floor or bottom. In others, but more rarely, it is scattered throughout a great thickness of the gravels and sands.

It is impossible to conceive the origin of the vast volume of gold-bearing solutions necessary to provide the gold, or the barriers capable of confining the solutions to narrow leads winding in a tortuous course through the drifts.

The authors of the precipitation theory maintain that alluvial gold is purer than vein-gold, and sometimes occurs in masses, or nuggets, of dimensions unknown in vein-gold. Recent investigation by the author has entirely disproved the first contention, so far as New Zealand is concerned; and the discovery of a mass of gold weighing 303 oz., in a quartz-vein near Coolgardie, some years ago, throws discredit on the assumption contained in the second.

The first gold discovered in the province of Auckland was alluvial gold, found at Coromandel. It was of poor quality, being alloyed with a large proportion of silver. Subsequently, when gold-bearing veins were discovered in the district, it was found that the gold was of poor quality, being in fineness and composition the same as the alluvial gold.

In Victoria, Western Australia, and California, the quality of the vein and placer gold is practically the same within the limits of variation to which gold in different parts of the same vein is subject.

With the more exact knowledge we now possess, concerning the occurrence of gold and formation of gold-drifts, we are unable to escape the conclusion that alluvial gold was originally derived from gold-bearing rock or veins, by a succession of natural operations identical with those that led to the production of stream-tin.

STREAM-TIN.

Origin of Stream-Tin.—Stream-tin originated from the surface disintegration and denudation of tin-bearing lodes, or of granitic masses containing tin-impregnations.

The Tin Placers of Malaysia.—The tin-fields of Malaysia are of great extent and value, the tin-bearing belt extending southward from Burmah and Siam, through the Malay Peninsula, to the outlying islands of Banca and Billiton, off the south-east coast of Sumatra.

The tin-bearing gravels are deposited on the floor of the valleys which intersect this rich zone of metalliferous country.

The geological features throughout are almost the same. The basement rock is granite, which is variously overlain by gneiss, schist, slaty shales, sandstone and limestone.[1] Tin-stone has been found *in situ* in veins traversing both the granite and slates, and disseminated as impregnations in the granite near the contact with the sedimentaries, and also in the limestone.[2] The stream-tin was manifestly derived from the tin-bearing veins and rock, and concentrated in the gravels by the rivers and their lateral streams.

In many places the gravels rest on a *false-bottom* of stiff kaolin, derived from the disintegration of the granite outcrops. They vary from 1 to 15 feet thick, and are overlain by an overburden ranging from 5 to 80 feet deep. The richness of the gravels varies from 5 lb. to 40 lb. per cubic yard.

The tin-stone of this region is very pure, generally containing from 70 to 75 per cent. of the metal. The colour is often black, and sometimes pale brown, or white. The ore is found in pieces of all sizes, from fine sand to boulders half a ton in weight. The associated minerals are magnetite and ilmenite.

The States of Perak, Selangor, Negri-Sembilan, Pahang, and the Dutch East Indies yield two-thirds of the world's production of tin. Of these, the State of Perak produces about one-third, and the State of Selangor one-third of the total output.[3]

The tin placers in the Kinta Valley, in the State of Perak, cover an area 40 miles long, and about 25 miles wide, and yield about three-fourths of the tin-stone raised in Perak. In 1904 Perak produced 26,400 tons of tin.

Other Tin Placers.—There are stream-tin mines in Burmah, Siam, and China, and in the Commonwealth of Australia, in the States of New South Wales, Queensland, Victoria, and Tasmania.

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[1] R. A. F. Penrose, Jr., *Journal of Geology*, Feb. 1903.

[2] Penrose, *loc. cit.*

[3] F. Owen, "Mining in Perak," *Trans. Inst. Min. and Met.*, vol. vi. p. 51.

The stream-tin deposits of Cornwall and Saxony have long been exhausted.

Platinum Placers.

Platinum in Russia.—Nearly 90 per cent. of the platinum of commerce is found as loose grains in the gravels of the rivers draining the eastern slopes of the Ural Mountains. The gravels generally contain some alluvial gold.

A little platinum has been found *in situ* in peridotite and olivine-gabbro, but not in payable quantity. Ultra-basic eruptives, and sometimes chloritic and talcose schists, prevail in the neighbourhood of the platinum placers; and fragments of these rocks predominate in the sands and gravels, thereby indicating pretty conclusively that the noble metal was derived from the adjacent area by the ordinary processes of weathering and erosion.

Platinum in America.—The domestic supply of platinum, in the United States, is obtained from the gold placers in Trinity and Shasta counties, California. The gold-drifts in Colombia, in South America, Brazil, British Columbia, and New Zealand also yield a small quantity of the metal.

Platinum is always alloyed with a small proportion of iridium, and often with a smaller amount of osmium.

Ironsand Placers.

Enormous deposits of black ironsand, mostly titaniferous, exist on the coast of Chili; on the north shore of the St Lawrence, in Canada; on the coast of California; and in New Zealand, on the coast between Taranaki and Wanganui.

These ironsand deposits were derived, in most cases, from weathered and denuded later eruptive rocks, near the coast-line. In some parts of the coasts of California and New Zealand, the black sands contain payable gold.

Gem Placers.

Diamond Placers.—River deposits yield diamonds, rubies, sapphires, and other precious stones. The diamonds of Brazil and New South Wales are obtained from gravels. The diamond placers of the Vaal River, in South Africa, yield gems of great size and purity.

Ruby Placers.—The principal ruby-producing region, in Burma, is situated near Mogok, about 90 miles due north of Mandalay. The rubies are usually found in a somewhat tenacious clay, or in material passing from fine gravel to river sand. The country rock is a very hard gneiss, passing in places into granite; or a soft friable micaceous schist.[1]

The district of Chantabun, in Siam, has long been famous for its ruby and sapphire mines.

Sapphire Placers.—In the sapphire fields of Anakie, in Queensland, the wash is often clayey, and sometimes friable and free from clay. In these deposits are also found other precious stones, notably ruby, diamond, topaz, peridot, moonstone, cat's eye, and cairngorm.

(*b*) *Massive.*

Deposits of this class occur as layers, or sheets, and irregular masses, lying on the surface, or covered with soils, surface clays, etc., of recent accumulation. They include deposits of bog-iron ore, and in some places, those of manganese and rock-phosphate.

Bog-iron Deposits.—Bog-iron generally occurs as irregular layers or lenticular masses, which were deposited in shallow lakes or swamps.

The iron, in the majority of cases, was derived from lodes or deposits of iron in the adjacent country. The decomposition of iron-bearing minerals has, doubtless, contributed its portion of iron. Extensive beds of bog-iron are often found near the outcrops of pyritic lodes, and of beds of the carbonate ore.

When iron pyrites is oxidised, a large portion of it passes into salts, soluble in water; while carbonate of iron is readily soluble in water containing dissolved carbonic acid. Atmospheric weathering must, therefore, daily liberate a large amount of iron in a soluble form.

It is well known that when chalybeate waters are exposed in shallow sheets, as in ponds, lagoons, and swamps, to the action of the air, the iron is deposited as the carbonate. Freshly precipitated iron may be frequently seen in stagnant pools in swamps. The precipitation is caused by the action of atmospheric carbon dioxide. In some cases the iron is thrown down as the hydrated oxide by decomposing vegetable products.

Bog-iron ores are porous, and cindery in structure. They contain, in many cases, too high a proportion of phosphorus to be useful for smelting purposes.

Action of Descending Waters.—Where superficial ore-bodies have been formed by the action of descending waters, it will be found, as a general rule, that the waters have merely acted

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[1] T. T. Wynne, "The Ruby Mines of Burmah," *Trans. Inst. Min. and Met.*, vol. v. 1897, p. 161.

upon and concentrated ores disseminated in the adjacent country rock. Such secondary concentration is often seen in the case of iron, manganese, and phosphate deposits.

A typical example of this class of ore-body is the great deposit of limonite at Parapara in New Zealand, which occurs as an irregular sheet of ore lying on the surface in a depression formed in Palæozoic schist. The original source of the iron is the schist and associated limestone.

Examples of the same kind are found in Pennsylvania.[1] The ores are largely limonite. They occur as rounded or elongated fragments with residual clay, in irregular deposits in cavities. The source of the iron is the Palæozoic shales and limestone in which the primary iron is disseminated in the form of carbonate, sulphide, and silicate.

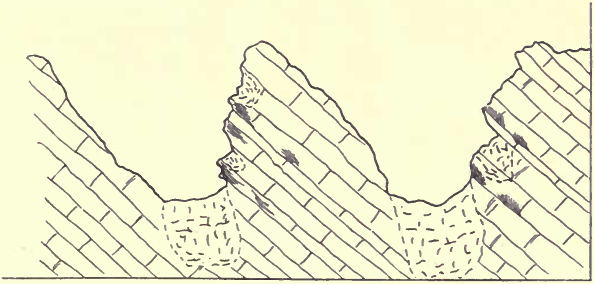

FIG. 12.—Section at the Pennsylvania Furnace Ore-bank, showing deposition of limonite by descending waters in the bedding and joint planes, and nodular iron ores in hollows in limestone. (After T. C. Hopkins.)

The manganese deposits of Cartersville in the Southern Appalachians of the State of Georgia, are among the most important in America. They occur embedded in a thick deposit of residual clays mainly derived from the decay of the Beaver limestone and Weisner quartzites of Cambrian age.

According to T. L. Watson,[2] the ore is distributed irregularly throughout the clays in the form of pockets, lenticular masses, veins and stringers, single nodules and concretionary masses; and as small disseminated grains. In extreme cases the largest pockets may yield as much as several hundred tons of ore. They are rarely composed of solid ore, the usual form being that of nodules thickly studded through the clay.

Of the manganese oxides which occur, pyrolusite and psilomelane

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[1] T. C. Hopkins, *Bulletin Geol. Soc. Am.*, vol. xi. p. 475.

[2] T. L. Watson, "The Manganese Ore Deposits of Georgia," *Trans. Am. Inst. M.E.*, vol. xxxiv. 1904, p. 222.

greatly predominate. Beds of limonite occur separately or in close association with the manganese oxides, forming manganiferous-iron ores of varying grades of purity.

The immediate source of the manganese is held by Watson and others to be rocks from which the residual clays enclosing the ores were derived. The dissolution and concentration of the manganese was effected by descending waters charged with oxygen, carbonic and organic acids.

In the Cave Spring district, in the adjoining county, the manganese ores are confined to residual clays derived from the Knox dolomite stratigraphically higher than the quartzites and limestones of Cartersville district. Massive cherty beds occur in the limestone in places, and the decay of the rocks in these places has formed manganiferous-chert breccias which, however, are not of much economic importance. The following figure shows the form of decay assumed by the Knox limestone which is ascribed to the Silurian period.

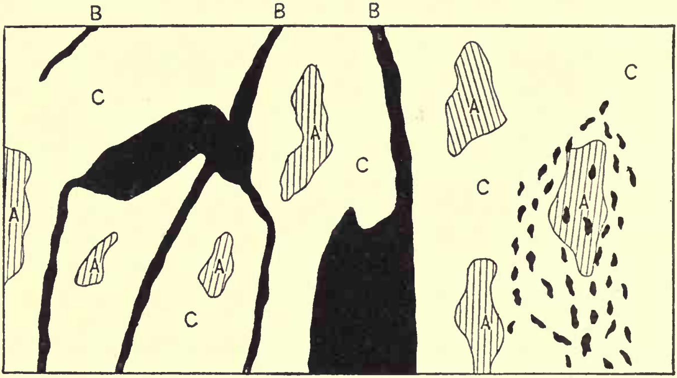

FIG. 13.—Section in one of the Openings at the Dobbins Mine, near Cartersville, Georgia, showing the occurrence of manganese ore in the residual clays. (Modified from Penrose by Watson.)

A, fragments and masses of partially decayed rock; B, manganese ore; C, residual clay.

Horizontal and vertical scale, 1 in. = 10 ft.

The important manganese ores of Romanéche (Saône-et-Loire) occur, according to De Launay,[1] both as veins which traverse the granite and as irregular sheets in red clays intercalated in limestone. The latter abut against a nearly vertical wall of granite. The vertical boundary between the granite and the Secondary

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[1] Professor L. de Launay, *Comptes Rendus, viii. Session Congrès Géol. Internation.*, Paris, 1901, p. 968.

rocks is occupied by a vein of manganese. These deposits appear to be partly contact ores and partly replacements of the limestone.

The valuable iron-deposits on the Mesabi range, near the north shore of Lake Superior, are believed to be due to secondary concentration by the action of descending water. Great bodies of ore lie on the surface and pass under heavy deposits of glacial drift.

Superficial Salt Deposits.—This sub-class also includes the surface deposits of salt in Asia, America, and Australia, as well as the valuable deposits at Lake Albert Nyanza, in Africa.

Borax Deposits.—A large proportion of the borax of commerce is obtained from muds and marsh sediments. The muds of Daggett, Pa., contain valuable deposits of sodium borate, as also do those of Turkey. The marshes of California and Nevada also yield a small output.

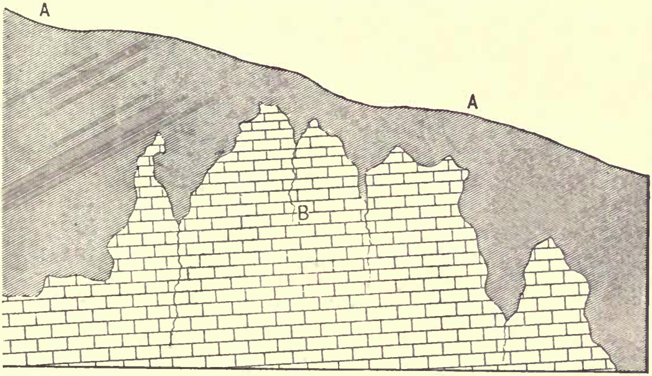


FIG. 14.—Section in Knox Dolomite, 2 miles east of Kingston, Georgia, illustrating decay of the magnesian limestone by flow of underground waters. (Modified from Spencer by Watson.)

A, residual clay; B, magnesian limestone.

Superficial Gypsum Deposits.—Gypsum is found forming thick beds on the floor of crater-lakes in volcanic regions. A notable example of this is seen at White Island in New Zealand, where the banks and floor of the crater-lake are covered with an incrustation of gypsum and sulphur many feet thick.

Gypsum also occurs as beds associated with calcareous and argillaceous rocks; and in disseminated crystals in clays and marls.

Sulphur Deposits.—Native sulphur occurs most frequently in volcanic regions often associated with sulphur and celestine.

It occurs in beds in the valleys of Noto and Mazzaro in Sicily; at Solfatara, near Naples; also in Java, Japan, and New Zealand.

Class II.—Stratified Deposits.

(*a*) *Constituting beds or strata.*
(*b*) *Disseminated through a bed.*

(*a*) *Constituting Beds or Strata.*

Strike and Dip of Beds.—A bed or seam is a member of a stratified formation, the overlying layer forming the roof, and the underlying the floor.

The *strike* of a bed or seam is the direction of a horizontal line drawn along the plane of the stratification.

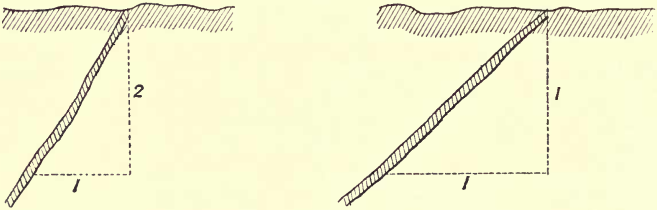
The *dip* is the direction towards which a bed inclines, and is always at right angles to the strike. If we assume that we are standing upon the outcrop of a vein, running or striking north and south, and facing north, it will be found that the dip may be either to the right or left, that is, to the east or west.

The *dip* or *direction of the inclination* of a bed or vein must not be confounded with the inclination or *angle of dip*.

The Inclination of Beds.—The *angle of dip* is the *downward* inclination measured in degrees from the *horizontal*.

The *underlie* is the downward inclination measured in degrees from the *vertical*.

The dip and underlie are only the same when the inclination of the bed or vein is 45°. The term underlie is in common use among miners, and is apt to lead to confusion if used carelessly.



Figs. 15 and 16.—Showing Inclination of Veins by Co-ordinates.

When describing a bed or seam a geologist will generally say, "The seam strikes north-south, and dips east at an angle of 25°." This means that the direction towards which the seam inclines is east; and the angle of inclination, measured from the horizon, is 25°.

The inclination of a bed or vein is often expressed in rectangular co-ordinates. For instance, a dip of 1 in 3 signifies a departure from the perpendicular of 1 inch, foot, or other unit, for every three of vertical depth; but the co-ordinate method must not be confused with the method of expressing railway or road gradients, in which a gradient of 1 in 1000 means a vertical rise of 1 foot in a distance of 1000 feet measured along the slope.

The inclination or angle of dip is generally measured with a clinometer (Abney level), or with a plumb-bob and foot-rule.

Thickness of Beds.—The thickness of a bed or seam is the length of a line, measured at right angles to the plane of the bedding.

For example: Suppose the measured horizontal distance in fig. 17 between the points *a* and *b* were 500 feet, then the thickness of the beds lying between points *a* and *b* would be equal to the length of *ac*; and if the average angle of inclination or dip of the beds, measured from the horizon, were 60 deg., that is, the angle at *b*,

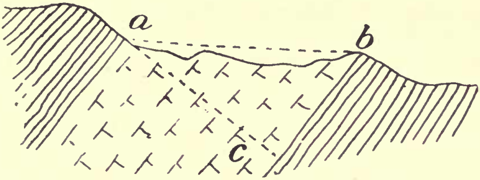


FIG. 17.—Showing Measurement of Thickness of Beds.

Then sin 60 deg. × 500 = ac = 433 feet.

Examples of Bedded Deposits.—The useful minerals which occur in beds, or as members of a stratified formation, are coal, oil-shale, and spathic iron. In addition to these, roofing slates, marbles, limestones, building stones, and natural cements are quarried for commercial purposes.

Coal.

Origin and Formation.—Coal is simply an altered form of vegetable matter. At one time it was believed that there was only one formation containing true coal, hence the origin of the geological time-name *Carboniferous*. The discoveries of recent years, however, have shown that coal occurs in rock of all ages; and the investigation of the newer coal-measures has led to the belief that coal-vegetation established itself wherever and whenever the conditions were favourable for its growth.

In tracing the succession of plant and animal life in geological time, it is found that the earlier forms were of a very primitive type. In ascending the geological scale, these earlier forms were succeeded, and to a large extent displaced, by more highly organised forms, doubtless better adapted to the prevailing conditions of the time and place.

In respect to plant-life, the Primary period was specially distinguished by the great development of mosses, ferns, and other cryptogamic forms; the Secondary period by the growth of cycads and ferns; and the Tertiary by deciduous trees and flowering plants.

The coals of the different geological periods are formed of the vegetation prevailing at that time. Hence the Carboniferous coals of Europe are composed of the remains of ferns, mosses, equisetums, lycopodiums, and lepidodendrons, many of which grew to a gigantic size, resembling in their habit the forest trees of the present time.

The great coal-deposits of Carboniferous age would indicate that plant-life in this period reached its maximum development, attaining a luxuriance unrivalled at any later geological period.

There is good reason for the belief that the coal-vegetation of this and all later periods grew on wide tracts of low-lying, swampy land, adjacent to some sea or lake, enveloped in a cloud of steaming vapour, through which the rays of the sun seldom penetrated.

Many of these ancient forests extended for hundreds of miles, occupying the estuaries and deltas of great sluggish rivers laden with mud and fine sediments.

A study of the coal-measures of every country and of every age reveals the fact that the accumulated coal-vegetation was preserved from destruction by the gradual submergence of the land, which thus permitted the deposition of a great thickness of protecting sediments.

The succession of seams met with in many coalfields indicates successive periods of minor subsidence and elevation of the land, each seam with its underclay marking the site of a new forest.

The thickness of the beds or strata between the different seams affords some evidence of the extent and duration of each submergence; but the clay partings met with in coal-seams cannot always be taken as an evidence of submergence. They may mark an encroachment of flood-waters on to the forests during an abnormal inundation, whereby a layer of mud was deposited among the vegetation, whose growth would be retarded, but not destroyed.

Mode of Occurrence.—The character of the sediments succeeding the coal naturally varied with the position of the forests and their proximity to the sea, even for coals of the same age.

Subsidence of the land was a fundamental requirement for the preservation of the accumulated coal-vegetation. In most countries, the coal is followed by shales or indurated clays, sandstones, and limestones.

The shales are commonly formed of fluviatile muds, which generally contain plant-remains; the sandstones are fluvio-marine, and often contain a rich molluscan fauna; while the limestones are composed of shells and corals, which indicate a true marine littoral. In these cases the coal marks the beginning of a cycle of deposition.

Where the coal-vegetation grew on the margins of lakes or in lake estuaries, the coal-measures consist principally of shales, grits, and sandstones. In most places the grits underlie the coal.

Age of Coal.—Carbonaceous matter is found in rocks of all ages, and in nearly all kinds of sedimentary rocks.

The graphite beds of Canada occur in rocks of Laurentian age. The anthracite of County Cavan, in Ireland, is Silurian; the great coalfields of Great Britain, Continental Europe, and United States are Carboniferous; the coals of New South Wales, State of Virginia, India, and China, Carboniferous and Permo-carboniferous; the bituminous coals of New Zealand, Upper Cretaceous; the brown coals of South Hungary, Pennsylvania, and North Germany, Oolitic and Liassic; of New Zealand and Vienna basin, Miocene; and the lignite beds of Ireland, Pliocene.

Inclined Position of Coal Seams.—The coal-measures, with their accompanying seams of coal, were originally deposited in a more or less horizontal position. If the strata had remained horizontal, it is evident that the task of procuring coal would have been very laborious and expensive; and in countries where the overlying strata are thick the coal could not have been reached.

The secular movements of the crust of the earth have tilted the strata at different angles, the dip varying from a few degrees to angles which occasionally approach the vertical.

Faulting of Coal Seams.—Sudden dislocations or changes of position are spoken of as *throws*, *troubles*, *slips*, or *faults*.

In coal-strata faults often occur in a series of two or more, having a parallel bearing. They sometimes all dip one way, but frequently in opposite directions.

Step-faults are often met with in coal-measures. Where the dislocations do not exceed the thickness of the coal-seam they are termed *hitches*.

Extent of Faults.—Fault-lines are often so thin as to be easily mistaken for the ordinary jointing of the beds which they traverse. More frequently, however, the opposite faces present smooth, glassy, slicken-sided walls, with a space partially or entirely filled with clay or *débris* derived from the adjoining rocks.

In many cases the faulting has been caused by lodes or cross-courses, which often contain threads or pockets of iron-pyrites, known to coal-miners as *brasses*; and, where they intersect a coal-seam, quantities of sooty coal mixed with clay.

Intrusive Dykes and their Effects.—Dykes consist of wall-like masses of igneous rock, often basaltic. They are vertical, or inclined at various angles, and sometimes act the part of faults by displacing the strata on the opposite walls. They sometimes run parallel to faults.

In the coalfields of Scotland sheets of basalt have been forced along the surfaces of coal-seams, and even along their centre, so as to form a bed or sheet in the middle of the seam.

Intrusive dykes and sheets or sills sometimes cause great loss of coal, and extra expense in the working of the seam.

The coal in the vicinity of an igneous mass is often coked, and rendered *cindery* or *sooty*.

But the effects are not always destructive. At Malvern Hills, in New Zealand, a seam of brown coal was dehydrated and converted into anthracite of good quality by a sheet of basalt.

Coal may also be altered by the same agency into graphite. Among the *débris* on the slopes of Mount Egmont, in New Zealand (a beautiful volcanic cone which is piled up to a height of 8000 feet upon a floor of the lower Tertiary brown-coal measures), masses of sandstone with adhering layers of graphite of fine quality are of not uncommon occurrence.

Igneous dykes often dam back water in coal-mines; and in some cases they have effectually prevented the spread of fire.

Irregularities of Coal Seams.—The troubles met with in coal-mining are known as *balks*, *nips*, *gaws*, *saddle-backs*, *swellies*, *pot-bottoms*, *horses*, and *shaken coal*.

Balks are sudden thinnings in the coal, occasioned by a depression of the roof of the seam, accompanied by a corresponding rising of the floor.

When the stratum above the coal invades the thickness of the seam, so as to almost or entirely take the place of the coal, it is called a *nip* or *want*.

Gaws and *saddle-backs* appear to be the reverse of nips, as the floor is either irregular or rises into and interferes with the continuity of the coal-seam.

In *swellies* and *pot-bottoms* the ordinary thickness of the coal is increased by a depression of the floor.

Coal-seams which rest close to the basement rock are always the most subject to irregularities in thickness. This is a very noticeable feature of the Auckland coalfields of New Zealand, where the seams of brown coal conform to some extent to the contour of the basement rock. The result of this conformity is that the coal thins where the basement rock rises in ridges, and thickens in the hollows. In the depressions the seam is sometimes 60 feet thick, and on the ridges only a few feet. The thickening and thinning of the seam does not necessarily imply that the coal is detrital, for it is manifest that the wet, spongy, peaty mass of vegetable matter from which the coal was formed would slowly gravitate towards, and accumulate in the hollows existing in the land surface on which the vegetation grew.

Shaken coal is coal which appears to have been completely crushed by some pressure or movement of the strata. It is often a mere heap of shapeless coal-dust, which is so soft that it may be dug out with a spade.

Bending of Coal Seams.—The effect of faults, volcanic intrusions, or lateral pressure due to the contraction of the crust of the earth has been sometimes to bend the coal strata, and in some cases throw them into complicated folds, which increase the cost of working, and cause a great waste of coal in mining. Examples of the folding of the strata in the anthracite coalfields of Pennsylvania are shown in the figs. 18 and 19.

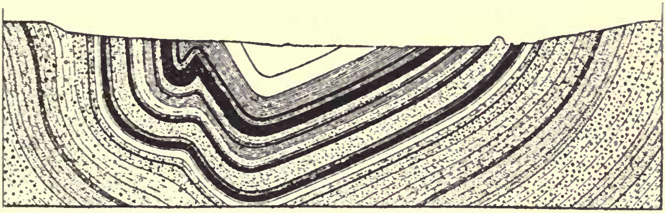


FIG. 18. — Cross-section of New Boston Basin, Pennsylvania anthracite region. (Reduced by B. S. Lyman from the cross-section sheet of the Pennsylvania Geological Survey.)

In fig. 19 we have an instructive example of inverted folding on the same coalfields.

The complicated manner in which coal-measures are folded is well illustrated in the coal-basin of Saint Eloy in France. A typical section of this field, drawn by De Launay,[1] is shown in fig. 20.

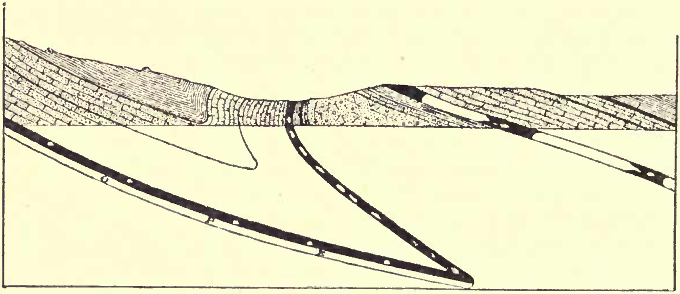


FIG. 19.—Cross-section Shenandah Basin, Pennsylvania anthracite region, showing inverted folding of coal-measures. (Reduced by B. S. Lyman from cross-section sheet of the Pennsylvania Geological Survey.)

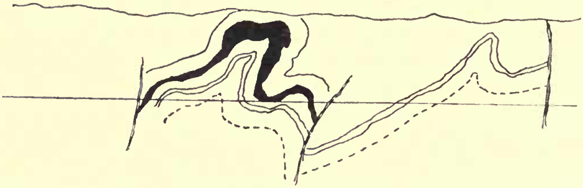


FIG. 20.—Section of Coal Basin, Saint Eloy. (After De Launay.)

Varieties of Coal and Influence of Enclosing Rock.—Assuming coal to be a form of altered vegetable matter, the progressive stages in its formation are indicated by the following kinds :—

(1) Peat.
(2) Lignite.
(3) Brown coal.
(4) Cannel-coal.
(5) Bituminous or caking coal.
(6) Semi-anthracite—smokeless coal.
(7) Anthracite.

The quality of a coal is not so much dependent upon the age of the coal as upon the thickness and lithological character of the coal-measures. A great thickness of close-grained impervious strata enables the alteration of the vegetable matter to proceed without

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[1] Professor L. de Launay, *Comptes Rendus, viii. Session Congrès Geol. International*, Paris, 1901, p. 959.

access of air or water, thereby producing coals of high quality without regard to age.

The fine bituminous steam-coals of the west coast of New Zealand, of Upper Cretaceous age, are enclosed in a great thickness of close-grained sandstones and shales. The coals of the same age on the east coast are enclosed in porous quartz grits, and are little better than lignite.

Another example of the influence exercised by the enclosing rocks upon the character of the coal is seen in the coalfields of eastern Texas.[1] In the Fayette, Yegua, and Timber Belt divisions, where the enclosing rocks are chiefly soft, sandy clays, and shales, the coal is only a lignite, while in Webb County where the measures are sandstones and shales, it is so superior as to be classed by Penrose in the bituminous group of coals.

(*b*) *Disseminated through a Bed.*

Sedimentary rocks containing well-defined horizons impregnated with ores and minerals of greater or less economic value are found in many parts of the globe. The origin of the metallic contents of these beds is a problem not yet satisfactorily determined. The metals were either introduced contemporaneously with the deposition of the sediments in which they occur, or after the consolidation and elevation of the sediments above water. The subject awaits further investigation. A few typical examples of this class of deposit are given below.

The Rand Banket Reefs.—In this class may be included the celebrated so-called *banket*, or almond, reefs of the Witwatersrand, in the Transvaal.

The basement rock is granite,[2] which is intruded by dykes of felsite, syenite, granulite, etc. The granite is overlain by the Quartzite-shale group, which consists of a great thickness of quartzite and ferruginous shales, dipping south, at angles varying from 20° to 50°. This group wraps round the north side of Johannesburg. It contains several thin conglomerate or banket beds, which are gold-bearing.

The Quartzite-shale group is followed, apparently comformably, by the Witwatersrand group—the gold-bearing series proper—consisting principally of quartzites, with which are associated beds of conglomerate or banket, sandstones and shales. The dip is south, at somewhat lower angles than the underlying series.

The Witwatersrand group is overlain by an enormous pile of amygdaloidal diabase, in its turn followed by the Black Reef

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[1] Heinrich Ries, *Mines and Minerals*, Scranton, Pa., Oct. 1905, p. 104.

[2] S. J. Truscott, *The Witwatersrand Goldfields*, 1898, p. 18.

formation. The latter consists of alternating quartzites and shale; and, at its base, contains conglomerates of the banket type varying from a few inches to 14 feet thick. It is separated from the diabase by a few inches of ferruginous clay.

The bulk of the gold in the Rand is derived from the Main Reef series, in the Witwatersrand group, which comprises three important banket reefs, namely:—

(*a*) The Main Reef (the lowest).
(*b*) The Main Reef Leader.
(*c*) The South Reef.

In addition to these, there are the less important bankets, known as the North Reef, the Middle Reef, and the Bastard South Reefs.

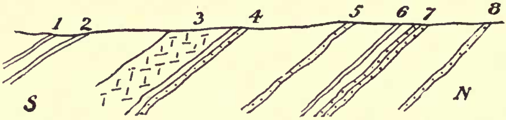

FIG. 21.—Cross-section across Robinson Mine. (After Gibson.)

(1 and 2) Bastard South Reefs; (3) Diabase Dyke; (4) South Reef; (5) Middle Reef; (6) Main Reef Leader; (7) Main Reef; (8) North Reef.

The banket beds consist of pyritic quartz conglomerates, composed of rounded or sub-angular pebbles of bluish-gray quartz, embedded in a quartzose matrix.

The Main Reef series comprises three more or less payable reefs or banket beds—namely, the Main Reef, which is often 12 feet thick, and very low grade; the Main Reef Leader, about 15 inches thick, and very rich; and the South Reef, varying from a few inches to 6 feet thick, and payable in most places. This series can be traced for 46 miles, and is the main source of the gold produced in the Transvaal.

A characteristic feature of the bankets is their uniform value. The even distribution of the gold has been an important factor in the development of the Rand goldfield. The gold does not occur in the enclosed pebbles but in the cementing medium—a circumstance which tends to show that the conglomerates are simply consolidated lacustrine or estuarine deposits, in which the gold was deposited from circulating gold-bearing solutions.

Mansfeld Copper Shales.—The copper-bearing shales (Kupferschiefer) of Mansfeld, in Prussian Saxony, are of Permian age. They are 18 inches thick, and extend for many miles. In places only the upper few inches are rich enough to pay. The copper contents vary from 2 to 5 per cent.

The ore is chiefly argentiferous fahlerz, but zinc blende, iron and copper pyrites, cuprite, and native copper are also present. It is believed by geologists that the copper was deposited contemporaneously with the shales, but the origin of the copper-bearing solutions is very difficult to explain, and the difficulty is increased by the wide distribution of copper-bearing rocks of Permian age in different parts of the globe.

Copper sandstones, of great extent, occur in Southern Russia, in many parts of Germany, in Great Britain and America, and all are believed to be of Permian age. The copper-bearing sandstones of the Keweenawan series near Lake Superior belong to a much earlier period.

Copper Conglomerates of Lake Superior.—The copper mines on the southern shore of Lake Superior, in the State of Michigan, have long been celebrated for their productiveness. Geologically, this copper region is highly interesting and instructive.

The copper-bearing belt, with a width varying from 4 to 5 miles, lies on a long peninsula, which projects into Lake Superior for a distance of some 60 miles. It consists of older Palæozoic sandstones and conglomerates, interstratified with sheets of eruptive rock, chiefly amygdaloidal diabase, and flanked by sandstones of Huronian age.[1]

The copper occurs almost wholly in the native state. It is found—

(*a*) Disseminated in beds of conglomerate and sandstone, which are intercalated with diabase flows.
(*b*) In old lava flows of amygdaloidal diabase.
(*c*) In veins which run at right angles to the general trend of the beds, and stand almost vertical.

In the beds of conglomerate and sandstone the copper occurs as the cementing material of the pebbles and grains of sand. In the Calumet and Hecla mine, which is the most productive, the bed of copper-bearing conglomerate varies from 8 to 25 feet thick.

The amygdaloidal rocks are everywhere much altered. The copper which they contain is very irregularly distributed, except in the Atlantic mine.

Silver Sandstones of Utah.—The silver sandstones of Utah, in Washington County, are as puzzling as the copper shales of

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[1] R. D. Irving, "The Copper-bearing Rocks of Lake Superior," *Monograph, United States Geological Survey.* Washington, 1883.

Europe. They consist of alternating shales and sandstones of Triassic age.

The White Reef and Buck-eye Reef are two sandstone beds, from 3000 feet to 4000 feet apart. Above water-level they are impregnated with kerargyrite, or horn silver; and below water-level the chloride is replaced by sulphides. The metal-bearing rock varies from 30 to 90 feet wide, and yields an average of 25 oz. of silver per ton. A small percentage of copper also occurs with the silver.

Nearly all geologists are agreed that the silver and copper were introduced subsequently to the tilting of the beds.

Lead Sandstone of Prussia.—The lead sandstone of Commern, in Rhenish Prussia, is believed to be lower Triassic in age. The rock is a white sandstone, of great thickness. The upper part is charged with small concretions, varying from a pin-head to a pea in size, composed of quartzose sand, cemented with galena.

The concretions are called *knots*, hence the miners' name, *knotten-sandstein.* They contain a little chromium, vanadium, and titanium; the latter in the greatest proportion. The ore is mined partly by open-cast and partly by underground workings.

Lead-bearing sedimentary rocks belonging to this class occur in several parts of Germany, and in the counties of Nottingham and Leicestershire, in England.

Beds containing Coprolites.—Coprolites are found disseminated in greensands interbedded with strata of younger Secondary age in the south of England. The coprolite bearing greensands of the Cretaceous Waipara series of New Zealand are of too low a grade to be of economic value.

Gypsum Beds.—Gypsum occurs in beds associated with calcareous and clayey rocks. It is found in great quantity in the Paris basin at Montmartre. Its occurrence in volcanic regions has already been noted.

CLASS III.—UNSTRATIFIED DEPOSITS.

(*a*) *Deposits of volcanic origin.*
(*b*) *Stockwork deposits.*
(*c*) *Contact and replacement deposits.*
(*d*) *Fahlbands.*
(*e*) *Impregnations.*
(*f*) *Segregated veins.*
(*g*) *Gash veins.*
(*h*) *True fissure veins.*

(*a*) *Deposits of Volcanic Origin.*

These include the deposits of sulphur and borax, which accumulate in and around fumaroles in the form of sublimates.

Notable examples of sulphur-deposits are found at Mount Etna and Mount Vesuvius; White Island and Rotorua, in New Zealand; and in Japan.

At White Island the bulk of the sulphur is of very low grade, being mixed with a very large proportion of gypsum. At Rotorua, thousands of tons of both yellow and black sulphur of high grade are being mined by the natives for export.

The steam fumaroles of Pisa and Grosetto, in Italy, yield a large annual output of boric acid.

(*b*) *Stockwork Deposits.*

The term "stockwork" was first used in Europe to distinguish the quarry-method of mining certain mineralised rock-masses intersected by small reticulating veinlets of ore. It no longer refers to the method of working, but is applied to metalliferous ore-bodies possessing the characteristics of the deposits first mined as stockworks.

A stockwork may be defined as a rock-mass traversed by numerous small veins of ore that mutually intersect each other, but are too small to be worked separately.

The veins seldom possess clearly defined walls, but merge imperceptibly into the country-rock which itself is often impregnated with mineral matter to a greater or less extent.

Stockworks are sometimes of great width and length. They are mostly of low grade; and from necessity are commonly worked by the quarry or open-cut system of mining, which enables a large output of ore to be produced at a small cost.

Alaska Treadwell Stockworks.—The celebrated gold-bearing ore-bodies in the Treadwell mines, Douglas Island, in Alaska, according to Spencer,[1] consist of mineralised dykes of albite-diorite lying between greenstone on the hanging-wall and slate on the foot-wall, with a few smaller dykes near by in the slate. They generally conform to the strike and dip of the slates.

The greenstones are, as a rule, greatly altered, and in places possess a schistose or slaty structure. They are supposed to be ancient andesites and basalts that were erupted at the time the slates were formed.

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[1] A. C. Spencer, "The Geology of the Treadwell Ore Deposits, Douglas Island, Alaska," *Trans. Am. Inst. M.E.* Pamphlet, 1904.

The ore mainly consists of altered diorite impregnated with sulphides, chiefly iron pyrites. The rock is also partly shattered and filled with a network of thin calcite and quartz veins that carry a fair proportion of sulphides.[1] The dykes are considerably mineralised, and often the whole mass can be mined. In general the best ore is that which contains the greatest number of calcite and quartz veinlets.

The gangue is felspar, calcite, and quartz. The gold is associated with about 2 per cent. of pyrites and some magnetite. Pyrrhotite often accompanies, or replaces, the pyrites.

The ore is of very low grade, averaging about twelve shillings per ton, but the large output, free-milling character of the ore, and skilful management have enabled the mines to pay handsome profits for many years. The ore-bodies are mined partly by open-cuts and partly by underground workings.

Other Stockworks.—At Zinnwald, in Bohemia, in a dome-shaped mass of greisen (quartz and mica), there are narrow, horizontal veins of tin-ore that form stockworks.

At Altenberg there is a greisen-like rock, locally called Zwitter, in which tin-ore is disseminated to the extent of one-third to one-half per cent., thus forming a stockwork. Somewhat similar deposits occur in granite in the form of impregnations.

Near Stanthorpe, in Queensland, grains of tin are disseminated through a granitic rock, as if forming one of its original constituents.

At Monte Catini, in Tuscany, the Cretaceous strata are broken through by serpentine and gabbro, containing large pockets of copper ore, mostly erubescite and copper pyrites.

In Cuba and Newfoundland rich deposits of copper occur in serpentine.

In Cornwall granites and slaty shales, locally called killas, containing from 8 lbs. to 9 lbs. of tin stuff to the ton of rock, yield a good profit. In some cases 2 lbs. of tin stuff have been sufficient to pay all expenses. A man can break from 1½ to 2 tons of the hard rock per day, and 7 to 8 tons of soft killas.

In the mineral belt near Nelson, in New Zealand, native copper and cuprite occur in serpentine, and chromite of iron in massive olivine.

At Kimberley, in South Africa, diamonds are found disseminated in tuffs and agglomerates occupying the necks of ancient volcanoes.

(*c*) *Contact and Replacement Deposits.*

A contact-deposit is one which occurs at, or near, the contact of a sedimentary rock and an intrusive mass or dyke.

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[1] A. C. Spencer, *loc. cit.*, p. 25.

Valuable deposits of magnetite, specular iron, and of copper, lead, and zinc sulphides are not uncommon along the junction between the intrusive and country-rock, frequently *near* the boundary, but *never outside* the metamorphosed zone.

In most, probably in all, cases the ore-body is a mineralised replacement of the country-rock following certain well-defined zones of fracture or crush which are genetically connected with the igneous intrusive mass. Petrological methods of examination have shown that progressive stages of alteration can be traced from the unaltered rock to the mineralised ore-body.

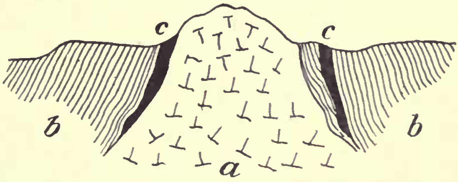

FIG. 22.—Section showing Contact Deposit.
(*a*) Granite. (*b*) Slate. (*c*) Contact Deposits.

The alteration, removal, and replacement were due to ascending highly heated waters laden with mineral matter derived from a deeper zone, probably the cooling intrusive rock-magma itself.

Valuable deposits of magnetite are found at the contact of impure limestones and granite, in the Christiania district, in Norway.

Near Framont, in the Vosges, in France, masses of specular iron are found wrapping round a boss of quartz-porphyry.

Pyritic Ore-Bodies. *Rio Tinto Copper Contact.*—Of pyritic contact-deposits the most typical in Europe are those of Rio Tinto, Tharsis, and San Domingo, in Spain, and adjacent part of Portugal, which occur at the boundary between altered slate and felspar-porphyry.

The famous copper mines of Rio Tinto are contained in a great belt of mineralised country, 140 miles long and 30 miles wide, stretching from Huelva, in Spain, into Portugal. The country is slate of Upper Devonian age, often locally altered into jasper, talc-schist, and chiastolite schist, and intruded by great masses of quartz- and felspar-porphyry diabase, quartz-syenite, and granite.

The ore is a fine-grained and compact iron pyrites, containing on an average less than 3 per cent. of copper. Small veins of copper pyrites, erubescite, and occasionally copper glance, more or less mixed with iron pyrites, quartz, blende, and other minerals, traverse the mass.

Contact Ores in America.—The argentiferous lead ores of Leadville, in Colorado, have been described by Emmons[1] as contact-deposits occurring along the contact planes of eruptive porphyry dykes, which have broken into and overlain a bed of dolomitic limestone.

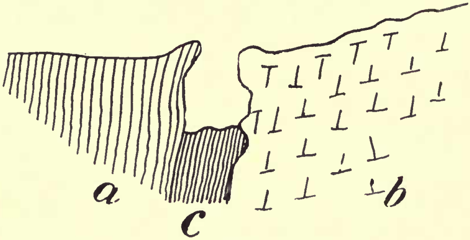

FIG. 23.—Section of Rio Tinto Pyritic Contact Deposit.
(*a*) Altered slate. (*b*) Felspar-porphyry. (*c*) Cupriferous pyrites.

The lead-zinc ores of South Mountain, in the State of Idaho, occur along the contact of limestone and diorite or granite. They have been described by Lindgren[2] as true contact-deposits.

In the Seven Devils district, in the same State, there are copper-deposits which occur as (*a*) fissure-veins, (*b*) zones of impregnation, and (*c*) contact-deposits. The country-rocks consist of Triassic slate and limestone, intercalated with basic lavas. In several places this series is intruded by diorites; and all the ore-bearing bodies appear to be genetically connected with these intrusive masses.

The sedimentary series, in different places, has been fissured in the zone of metamorphism, and also outside of it. The fissures, in the zone of metamorphism, when filled with mineral matter, formed contact-deposits, while those outside of it became fissure-veins. Morphologically they differ, but genetically they are the same.

The valuable copper deposits of Arizona occur associated with Carboniferous limestone, generally at the line of contact of granite, or other eruptive rock.

Gold- and copper-bearing contact-veins are common in Mexico, occurring generally between Cretaceous limestone and eruptive rocks, which are nearly always diorite.[3]

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[1] S. F. Emmons, "The Genesis of Certain Ore Deposits," *Trans. Am. Inst. M.E.*, vol. xv., p. 125, 1886.

[2] W. Lindgren, "The Genesis and Character of Certain Contact Deposits." *Trans. Am. Inst. Min. Eng.*, vol. xxxi. p. 226; and "Genesis of Ore Deposits," p. 721.

[3] Lindgren, *loc. cit.*, p. 724.

Rammelsberg Pyritic Deposit.—Pyritic ore-bodies associated with, but not actually in contact with, eruptive masses, are found in all parts of the world. Of such ore-bodies that at Rammelsberg, in the Hartz, said to have been worked for 900 years, Mount Lyell lodes, in Tasmania, and the Broken Hill lode, in New South Wales, may be cited as typical examples.

Vogt[1] describes the Rammelsberg deposit as an irregular lens of ore with a curious lateral branch like the Broken Hill lode. The deposit is 1500 yards long and from 49 to 65 feet wide. It is enclosed in Upper Devonian slates, occupying the centre of a *shear zone.* Its genesis is believed by Vogt to be closely connected with certain lines of eruption of granite in the immediate neighbourhood.

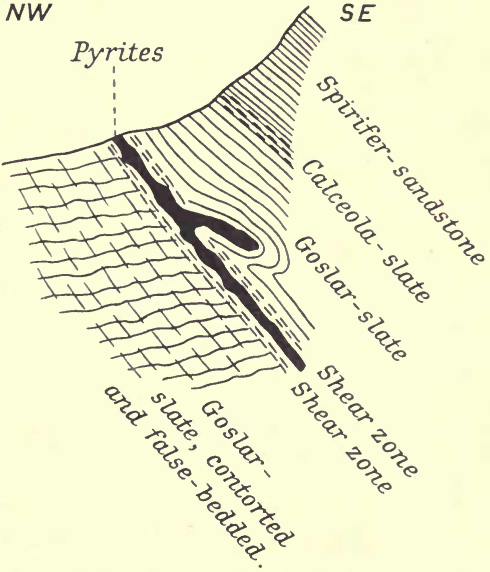

FIG. 24.—Ideal Section of Rammelsberg Pyritic Deposit. (After Vogt.)

Mount Lyell Ore Deposits.—Professor J. W. Gregory[2] groups the ore-deposits of this district into two classes, namely, (*a*) huge, lens-shaped pyritic masses, and (*b*) mineralised bands of schist,

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[1] Professor J. H. L. Vogt, "Ueber die Kieslagerstätten vom Typus Röros, Vigsnäs, Sulitelma in Norwegen und Rammelsberg in Deutschland," *Zeit. Prakt. Geol.*, 1894.

[2] Professor J. W. Gregory, "The Mount Lyell Mining Field—Tasmania." *Trans. Aust. Inst. M.E.*, vol. x., 1905, p. 26.

forming fahlbands. The former are the source of the great bulk of the valuable mineral mined in the field; the latter are economically of little importance.

The rocks consist of Devonian conglomerates and quartzites flanked by Silurian and Cambrian schists. The structure is not complicated by folding, but the country is traversed by a complex of great faults.

The ore-bodies occur as detached masses along the line of contact of the quartzites and conglomerates on the east, and schists on the west side.

Of the two main pyritic masses, the largest and most important is known as the *Big Mine* or *Parent Mine.* Professor Gregory describes it as irregularly boat-shaped in form, being an elliptical mass which tapers gradually downwards and is then cut off with a rounded base. The extension in depth is limited by a great thrust plane which brings the conglomerates under the ore and schists.[1]

The oxidised gossan consisted mainly of silica, barite, and iron oxide containing about 15 oz. of silver and 15 dwt. of gold per ton.

The pyritic ore is chiefly pyrites with copper, gold, and silver. Small patches of very rich ore, probably the result of secondary enrichment, were met with at the bottom of the oxidised zone. They contained redruthite, bornite, fahlore, and argentite.

The main pyritic mass is of very low grade. It contains from 0·5 to 2 per cent. of copper, from 1·5 to 3 oz. of silver, and from 0·04 to 0·07 oz. of gold per ton of ore.

W. T. Batchelor[2] states that a feature of the ore-bodies is their peculiarity of splitting into one or more legs or branches as they descend, a feature so characteristic of the Broken Hill lode in New South Wales.

The genesis of the Mount Lyell ore-bodies is still a question of doubt. Professor Gregory thinks they may be classed as contact-deposits, although not directly connected with igneous masses. The main ore-body lies in a *crush-zone* at the contact of the quartzites and schists, and its formation may possibly be connected with the granite intrusions of Mount Heemskirk range. A petrological examination of the wall-rock and ore would probably show that the Mount Lyell ores, like those of other pyritic masses elsewhere, are metasomatic replacements of the enclosing rock.

The great faults which traverse the lodes are thought by some writers to have a genetic association with the ore-bodies, but this connection has not yet been proved. The manner in which the lodes are faulted and displaced horizontally by thrust-faults

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[1] *Loc. cit.*, p. 118.

[2] *Loc. cit.*, p. 141.

would lead to the conclusion that the faults are of later date than the ore-deposits which they displace.

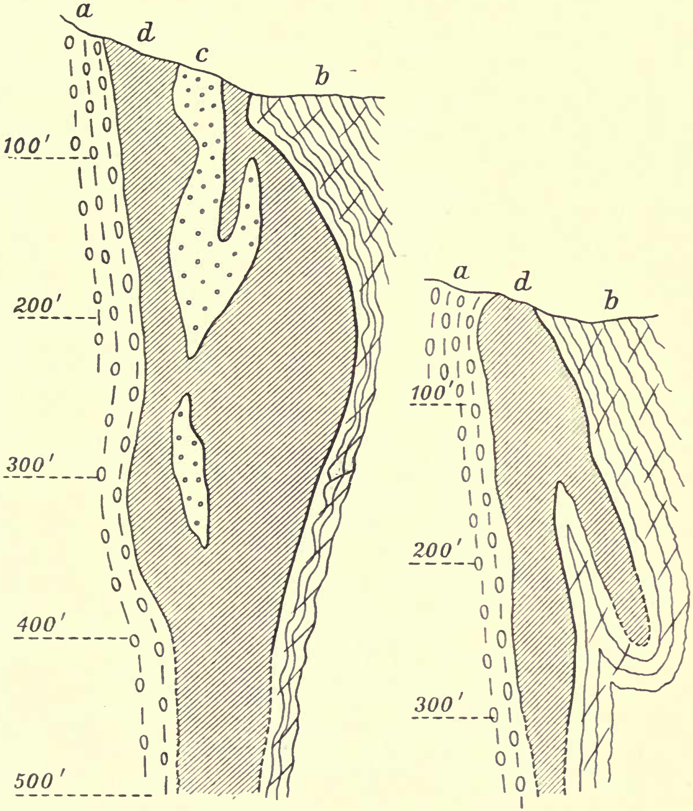

Fig. 25.—Cross-section of Mount Lyell Ore Deposits. (After Batchelor.)

(*a*) Quartzites and conglomerates. (*b*) Schists. (*c*) Isolated masses of quartzite enclosed in lode. (*d*) Pyritic ore-bodies.

Broken Hill Lode.—Broken Hill itself is a ridge, about 2 miles long, flanked on both sides by the plain. The rocks are mainly slates, schist, and gneiss, of probably Silurian age. The summit of the hill is crowned by the oxidised outcrop or gossan of the lode, which was impregnated more or less with cerussite, embolite, and iodyrite.

In the oxidised zone, below the ironstone cap, the mineral contents were principally cerussite, native silver, chlorides, bromides, and iodides of silver, associated with kaolin, garnet, and quartz.

Below the oxidised products came what are locally termed sooty sulphides, consisting of loose aggregates of galena and blende, enclosed in a gangue of quartz and garnet. The friable sulphides passed downward into solid sulphides (blende and galena), enclosed in a gangue of quartz, garnet, and rhodonite, containing also iron pyrites, and a little chalcopyrite. The sooty sulphides were frequently very rich, and apparently represented a zone of secondary enrichment.

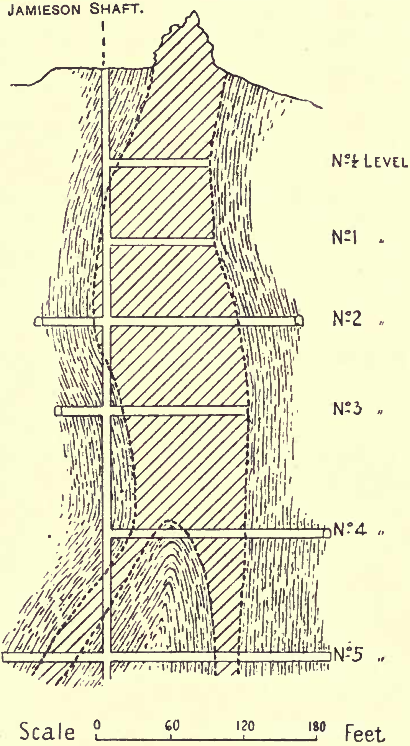

FIG. 26.—Cross-section of Broken Hill Lode—Broken Hill Proprietary Mine. (Copied from the Company's plan.)

Between the 200 and 300 feet levels, the lode divides into two spurs or branches, which follow the trend of the enclosing rocks.

The walls of the lodes are not slicken-sided. In many places the rock is impregnated or replaced more or less with ore.

The gneiss and schist are associated with numerous dykes of diorite,[1] to the intrusion of which the folding of the rocks and subsequent filling of the cavities along the axial line of main flexure may be ascribed.

The character and genesis of this lode is still a matter of disagreement among Australian geologists. Pittman and Jaquet[2] contend that the lode is a large saddle-reef enclosed in altered sedimentaries. Professor Gregory,[3] on the other hand, maintains that the position of the lode has been determined by a series of powerful faults along which mineralisation has taken place. He contends that the containing rocks are not sedimentary and never were. The gneisses and schists beside the lode are, he affirms, a series of altered igneous rocks. Pittman and Jaquet oppose this view with the statement that the same, or similar gneisses and schists, in the adjacent district, contain bands of limestone which clearly prove a sedimentary origin for the series.

Duckton Ore Deposits, Tennessee.—The pyritic ore-bodies in this region may be taken as typical of this class of ore-deposit in America. The rocks consist of gneiss and micaceous schists or slates which have been thrown into close folds.

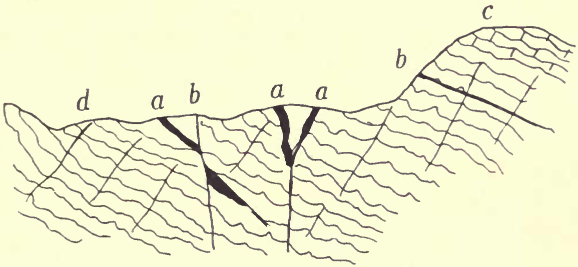

Fig. 27.—Ideal Section, N.W. to S.E., showing probable structure of Duckton region. (After Henrich.)

The ore-bodies consist of masses of pyrrhotite with which occur sulphides of copper, zinc, and lead. The portions near the surface have been oxidised into gossan. Carl Henrich[4] states that below

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[1] J. B. Jaquet, "Geology of the Broken Hill Lode and Barrier Ranges Mineral Field, New South Wales," *Memoir Geol. Survey N.S. W.*, No. 5, 1894.

[2] E. F. Pittman and J. B. Jaquet, "The Genesis of Broken Hill Lode," *Australian Mining Standard*, October 1904.

[3] Professor J. W. Gregory, F.R.S., "The Genesis of Broken Hill Lode," *Melbourne Argus*, September 1904.

[4] Carl Henrich, "Ducktown Ore Deposits and Treatment of Copper Ores," *Trans. Am. Inst. M.E.*, vol. xxv., 1896, p. 206.

the gossan and above the unaltered sulphides there is a zone of secondary enrichment consisting of partly oxidised copper ore or "black copper." Frequently a floor of white quartz occurs below the enriched zone frequently containing dispersed grains or bunches of marcasite.

The ore-deposits do not occur in direct association with igneous intrusions, but are found along the planes of fault-fissures, the fault-plane in all cases, according to Henrich, forming the east or hanging-wall of the deposit, which is always sharply defined. That writer is of the opinion that the Duckton ore-deposits are replacements of igneous dykes which at one time occupied the present places of the ore-bodies.

(*d*) *Fahlbands.*

These are beds or strata of crystalline metamorphic rock, so highly impregnated with ore as to be of commercial value. The silver-bearing fahlbands (or gray beds) of Norway are among the best-known examples. They follow, more or less closely, the strike and dip of the gneissoid and schistose strata by which they are bounded. They extend for several miles, and in cases attain a width of several hundred feet.

In the Kongsberg district these bands are crossed nearly at right angles by narrow fissure veins, varying in width from a few inches up to 2 feet, and are productive of silver only where they intersect the fahlbands. The fahlbands are important in this district solely from the fact that the small fissure-veins are enriched in passing through them, more especially when two such veins intersect within the mineralised belt.

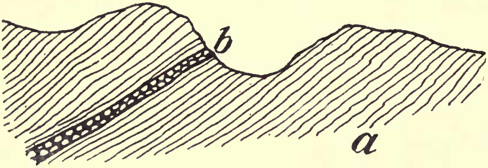

Fig. 28.—Section of Fahlband at Dusky Sound, New Zealand. (After Park.)
(*a*) Schists. (*b*) Fahlband.

At Dusky Sound, in New Zealand, there is a mineralised band of mica and chlorite schists, containing pyrrhotite, pyrite, with a little chalcopyrite and nickel, associated with epidote and garnet minerals. The band can be traced southward, across the mountains, for several miles, but it has not yet been shown to contain payable ore of any kind.

Fahlbands are related to bed-impregnations, which probably owe their origin to aqueous and gaseous emanations arising from a cooling intrusive magma.

(*e*) *Impregnations.*

It has sometimes happened that when a rock has been cracked or fissured a portion of the rock on one or both walls has become impregnated with some metallic substance, disseminated as grains, nests, or bunches throughout the mass in the vicinity of the fissure.

Such an occurrence is called an *impregnation*, implying that the mineral has been introduced as a secondary product by mineral waters or superheated steam.

The term impregnation implies a reference to the genesis rather than the form of an ore-deposit, and when used in a morphological sense is somewhat vague and meaningless. Genetically the majority of stockworks, contact-deposits, and fahlbands may be properly regarded as impregnations, as well as the Silver Sandstones of Utah, the Copper Conglomerates of Lake Superior, the Copper Shales of Mansfeld, and the Gold Bankets of the Rand, all of which probably derived their metallic contents from aqueous and gaseous emanations expelled from a cooling magma.

Tin Impregnations.—The ore most frequently found as an impregnation is cassiterite or tin-stone, and the rock in which it occurs in this manner is commonly granite. Many examples of this class of tin-deposit are met with in Australia and in Tasmania.

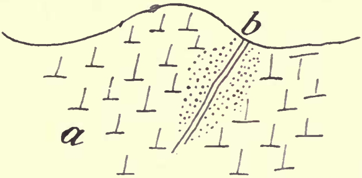

Fig. 29.—Tin Impregnation.
(*a*) Granite. (*b*) Tin impregnation.

At Mount Wills, in Victoria, tin-ore is found in veins and in disseminated grains in a granite, forming a true stockwork.

At Vegetable Creek, in New South Wales, it is found filling contraction cracks and joints in a granite, near the junction with clay slates. In the Emmaville division, in the same State, the tin-bearing ore occurs in veins and impregnations in the outer crust of a granitic boss.

In the Herberton district, which produces the bulk of the tin raised in Queensland, the tin-stone occurs in veins, bunches, and impregnations in granite.

At the famous tin-mine, at Mount Bischoff,[1] the tin-stone occurs in strings, bunches, veins, and impregnations in quartz-porphyry, eurite, and topaz-porphyry, which have intruded slates, sandstones, and quartzose rocks.

Impregnations, like fahlbands, form a group of metalliferous deposits not very clearly defined. Genetically, they are closely related to contact-deposits.

(*f*) *Segregated Veins.*

Deposits of this kind generally occur in the shape of lenticular masses, and often succeed one another in length and depth in such a manner as to constitute a more or less continuous vein. They are only found in sedimentary rocks that have been sharply folded, whereby cracks or fissures have been formed more or less parallel with the bedding planes, and dipping at right angles to the axial line of elevation.

Characteristics of Segregated Veins.—The chief characteristics of segregated veins are as follows :—

(1) Uncertain both in depth and linear extension ; that is, they are seldom continuous either in length or depth, but occur as a succession of disconnected, lentil-shaped masses, which may contain a few tons, or many thousands of tons, of quartz.
(2) Irregular in width.
(3) Seldom possess more than one well-defined wall.
(4) Frequently receive small veins in their course.
(5) Conform more or less to bedding planes of country-rock.
(6) They are only found in bedded sedimentaries, which are generally slates, claystones or sandstones.

Origin of Segregated Veins.—The origin of segregated deposits of this class is somewhat obscure. They generally occur along the bedding-plane of the country-rock. The cavities they fill have apparently been formed by the folding of the enclosing rock ; and this folding may have been caused by secular earth-movements, or the intrusion of an igneous mass.

New Zealand Segregations.—The productive quartz-veins

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[1] H. W. F. Kayser, "Mount Bischoff," *Aust. Assoc. Advt. Science*, 1892.

in the Reefton, Inangahua, and Lyell goldfields consist of a succession of lenticular masses which generally conform to the bedding planes of the enclosing claystones and sandstones. Some of the larger ore-bodies swell out to a width of 20 feet at their widest part, but the majority are shaped like flat lenses with a thickness varying from 3 to 6 feet. There are no dykes or intrusive bosses in the vicinity of the veins, which occupy cavities formed along the bedding planes of a monoclinal.

Saddle Reefs.—These are so named from their resemblance in form to a stockman's saddle. They are merely segregated veins formed in cavities along the bedding planes of sedimentary rocks which have been bent into anticlinal and synclinal folds.

E. J. Dunn,[1] who worked out the morphology of the saddle-reefs of Bendigo goldfield, in Victoria, defines a saddle-reef as:—"A lenticular quartz-lode lying between bedding planes of rock, bent over in anticlinal or synclinal folds."

The chief characteristics of saddle-reefs are as follows:—

(1) They occur in bedded, banded, or foliated rocks.
(2) They fill cavities which conform to the planes of bedding or foliation of the rocks.
(3) The greatest mass of ore occurs along the crown of the anticlinal arch forming the *saddle* from which the *legs* descend, one on each side of the arch.
(4) The legs diminish rapidly in size as they descend, and finally die out.
(5) Two or more saddle-reefs may succeed each other in vertical depth under the axis of the same anticlinal fold.
(6) The greatest thickness of ore in inverted saddle-reefs, formed in synclinal folds, is found along the axis of the trough.

The saddle-reefs of Bendigo consist of arch-like masses of gold-bearing quartz conforming to the bedding planes of the enclosing slate and sandstone of Silurian age. Dunn has shown that in most cases the folding of the rocks was caused by the intrusion of igneous dykes.

Inverted Saddle Reefs.—The gold-bearing veins at Cape Terawhiti, near Wellington, in New Zealand, are interesting examples of saddle-reefs which exhibit both an anticlinal and synclinal arrangement, as shown in fig. 31.

The rocks are Triassic claystones and sandstones which have been eroded into steep ridges and deep valleys, with the result that the veins have been correspondingly denuded. The ore-bodies

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[1] E. J. Dunn, *Report on Bendigo Goldfield*, Dept. of Mines, Victoria, Melbourne, 1893.

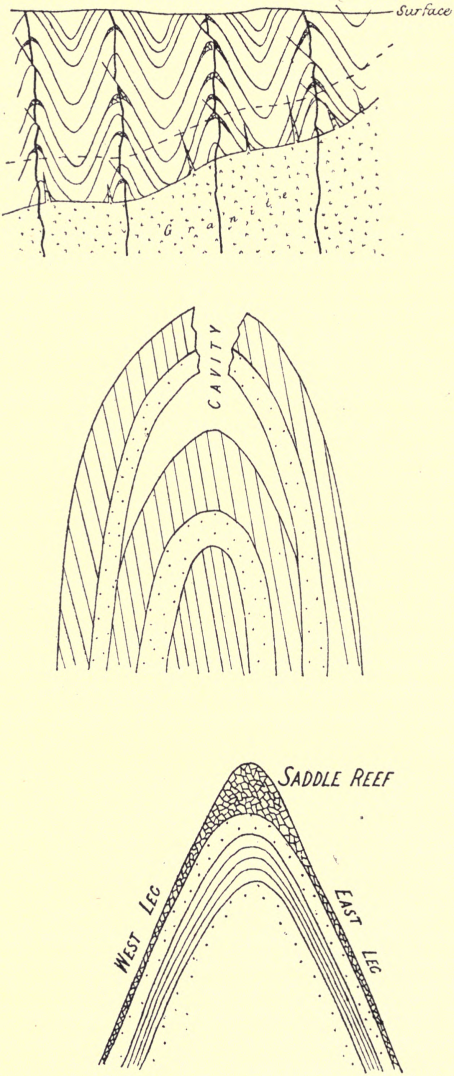

FIG. 30.—Sections showing Formation of Saddle-Reefs. (After E. J. Dunn.)

now remaining are only the truncated ends or legs of what were at one time true saddle-reefs.

The Monte Christo lode, in Nerrena, or Little Bendigo goldfield, is a segregated ore-body which sends out peculiar parallel lateral spurs or branches into the adjoining slates and sandstones. The form assumed by lodes of this class is always determined by the shape of the original cavity.

Fig. 31.—Section at Cape Terawhiti.
(*a*) Segregated veins.

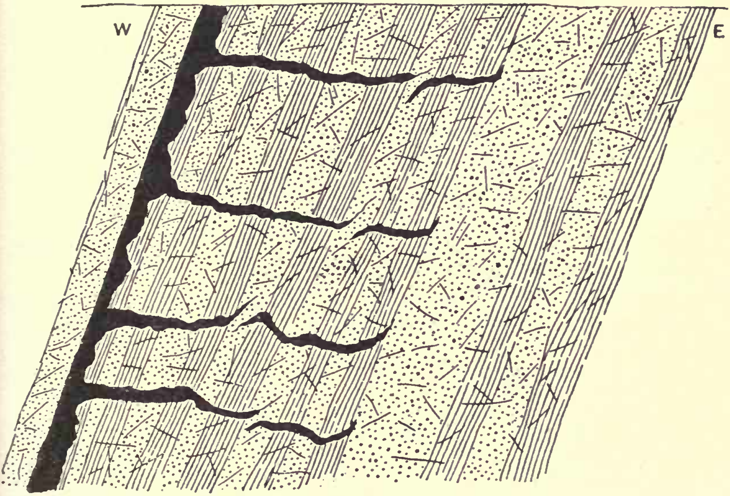

Fig. 32.—Cross-section of Monte Christo Lode, Little Bendigo. (After W. Bradford.)

(*g*) *Gash Veins.*

These are metalliferous deposits occupying lenticular or wedge-shaped cavities, or gashes in limestone. They generally occur along the bedding planes, often at the points of intersection of cross-joints where cavities, and sometimes large caverns, have been formed by the action of surface waters charged with carbonic acid.

The ores most commonly found in gash-veins are galena and zinc blende. Veins of this class have no distinct walls, and, being confined to a single stratum of the formation in which they occur, are limited in extent.

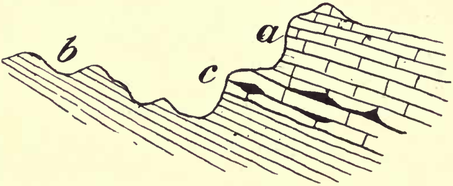

Fig. 33.—Gash Veins, Wangapeka, New Zealand.

(*a*) Silurian limestone. (*b*) Silurian slates.
(*c*) Gash veins containing galena and blende.

(*h*) *True Fissure Veins.*

Veins of this class are generally admitted to have originated in fissures caused either by secular folding, or by igneous intrusions, and are believed to possess great depth. They pass through all kinds of rocks in their course, independently of any bedding or stratification; but in some part they may chance to coincide with the dip and strike of the containing formation.

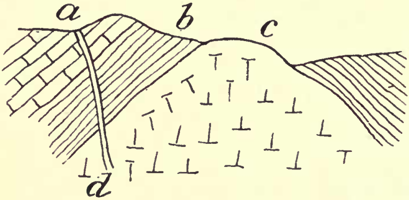

Fig. 34.—True Fissure Vein.

(*a*) Limestone. (*c*) Granite.
(*b*) Slates. (*d*) Fissure-vein.

The mineral contents of these veins were deposited from ascending aqueous solutions, which were, probably, genetically connected with deep-seated magmatic intrusions.

The banded arrangement of the vein-matter of the fissure-veins of Cornwall is very similar to that of the solfataric veins of the Hauraki goldfields, which would tend to show that the filling took place in the later stages of the after-actions following the igneous intrusion.

The two walls do not always coincide, that is, the fissure is often a fault, and of variable width. A true vein, like a segregated vein, may throw out spurs or branches from one or both walls.

Lodes of Cornwall.—The lodes of Cornwall are familiar examples of true fissure-veins. They pass in depth successively through limestone, slate, and granite. In the limestone, the principal commercial product was lead; in the slate, copper; and in the granite, tin.

Lodes of Bavarian Forest.—The three gigantic quartz lodes on the slopes of the Bavarian Forest are regarded by Suess[1] as the greatest monuments of linear dislocation known in Europe. They are true fissure-veins, and are believed by that distinguished geologist to occupy great fault-fractures, on the existence of which he finds support for his celebrated theory of mountain building by *horsts und graben.*

Of these, the Asch lode begins in the most north-westerly part of Bohemia, north-west of Asch, runs to the south-east transversely across the mica-schist, gneiss, and granite of Erzgebirge Mountains; then cuts across the narrow outcrop of gneiss near Seeberg, disappears beneath the Tertiary covering in the basin of Franzensbad and Eger, and reappears immediately on the other side of this in the granite mass of Sandan, finally extending through this up to the south of Königswart. The total length of outcrop is nearly 25 miles.

Near Hals, where the Asch lode ends, there appears the beginning of the great vein known as the Bohemian Pfahl which strikes south-south-east, then curves to the east, then turns back to the straight course and crosses the Bavarian frontier near Furth. The length of outcrop is about 34 miles, and the average width about 100 feet. For a long distance the lode runs between the gneiss and hornblende rock, but where the hornblende rocks bend, it passes completely into the latter.

The third and greatest of these lodes is the Great Pfahl. It strikes N. 58° W., and for the greater part of its course varies from 225 to 370 feet wide. For a distance of 27 miles in a south-east course, it separates the granite from the Triassic and middle Jurassic strata, and then to the west of the chain passes completely into the Archæan region; thence it continues in a straight line as far as the Austrian frontier. The total length of outcrop of this remarkable lode is 92 miles.

Veins of Cripple Creek.—The gold-bearing veins at Cripple Creek, in Colorado, traverse andesitic tuffs and phonolite of lower

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[1] Eduard Suess, *The Face of the Earth*, English edition, vol. i. p. 207.

Tertiary age. They are fissure-veins, grouped around old volcanic centres of eruption.

The Comstock Lode.—The celebrated Comstock lode, in Nevada, traverses propylitised andesite, dacite, diabase, diorite, etc., of older Tertiary age. In the middle portion of its course it occupies the line of contact between masses of diorite and diabase, the latter lying on the hanging-wall. The basement rocks are granite, schists, slates, and limestones.[1]

The lode has been traced for a distance of over 22,000 feet in a nearly due north and south direction. It dips towards the east, and has a thickness varying from 20 to 60 feet. The vein-fissure is also a fault. The vein-matter consists of crushed and decomposed rock, clay, and quartz. The lode is remarkable for the high temperature of the mine-water in the lower levels.

The mines on the Comstock lode have yielded a fabulous amount of gold and silver since they were opened in 1859. The gold exists as free gold, associated with sulphides of silver.

Mother Lode of California.—The Great Mother lode of California is one of the most remarkable fissure-veins in the globe. It is traceable for a distance of 70 miles, extending through five counties, and in many places is a mineralised belt, rather than a true vein.

This immense vein, or group of veins, generally occurs in a belt of black slate of Triassic age, and runs nearly parallel with the planes of stratification, dipping in the same direction at nearly the same angle of inclination. At different parts of its course, it traverses slate, diorite, diabase, serpentine, and granite.

The mines on the Mother lode and the rich placers on its course have yielded a large proportion of the gold produced in California for many years.[2]

Lode Formations of Kalgoorlie.—The famous lode-formations of Kalgoorlie in Western Australia possess many features of peculiar interest to the mining geologist. They are grouped together in an area about a square mile in extent, locally named the *Golden Mile*. The country-rocks in this area have undergone extreme alteration, which renders the determination of their original character very difficult.

In the oxidised ground, there is no sharp line of demarcation between the lode-formations and the country-rock,[3] which is

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[1] G. F. Becker, "Geology of the Comstock Lode and Washoe District," *Monograph iii. of U.S. Geol. Survey.* Washington, 1882.

[2] J. D. Whitney, *The Auriferous Gravels of the Sierra Nevada of California*, Cambridge, U.S., 1880, p. 45.

[3] H. C. Hoover, "The Superficial Alteration of Western Australian Ore Deposits," *Trans. Amer. Inst. Min. Eng.*, vol. xxviii. p. 785.

generally admitted to be of an eruptive character, probably of an acidic hornblende type.

The lode-formations are believed by some to be belts of country-rock, more altered and mineralised than the remaining rocks; by others to be igneous dykes which intruded the older eruptives, and subsequently became mineralised by ascending thermal waters in the waning or solfataric phase of eruptive after-actions.

The schistose structure observed in the lode-matter may have been induced by tangential stress due to secular folding and elevation, subsequent to the formation of the lodes. The presence of sericite favours the view that it was induced by pressure.

The evidence available at present seems to suggest that metasomatic replacement on a large scale, operating along lines of fracture, probably contraction fissures, played an important part in the genesis of the Kalgoorlie lodes.

The oxidised portion of the lodes extends from 50 to 400 feet below the present surface, the depth to which it extends being apparently independent of existing water-level or surface contours.[1] The gold in it is free and extremely fine. Generally speaking, the richer and more heavily mineralised parts are found to be oxidised to the greatest depth.[2]

In the oxidised zone the lode-matter consists chiefly of hydrated oxides of iron, hydrated silicates of alumina, and magnesia.[3] Calcite, sericite, chlorite, and other alteration products are also present.

The lode-formations are often intersected by small veins of decomposed quartz,[4] and Woodward states that it is where these are met with that the ore is richest.

The ore-bodies, or courses of rich ore, occur in irregular lens-shaped masses, varying from a mere thread to many feet in width. They are not continuous, but occur in echelon—one lens overlapping the other.

Below the oxidised zone the lodes are more clearly defined, particularly in the richer mines.[5] The country-rock is massive, but extremely altered, while the lode-matter is schistose, in places showing alteration to chlorite and sericite, and plentifully charged with disseminated iron pyrites.

In some mines the vein-filling consists chiefly of quartz.[6] The

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[1] H. C. Hoover, *loc. cit.*, p. 758.

[2] H. P. Woodward, "The so-called Lode Formations of Hannan's and Telluride Deposits," *Trans. Inst. Min. and Met.*, vol. vi. p. 17.

[3] *Loc. cit.*, p. 16.

[4] E. F. Pittman, "Notes on the Geology and Mineral Deposits of Portions of Western Australia," *Records of Geol. Survey of N.S.W.*, vol. vi. p. 1.

[5] W. Frecheville, "Notes on a Visit to the Gold Mines at Kalgoorlie, Western Australia." *Trans. Inst. Min. and Met.*, vol. vi., 1898, p. 141.

[6] *Loc. cit.*, p. 144.

quartz, however, is in many cases replaced by calcite, which is an important gangue material, sometimes occurring in large masses, with calaverite.[1]

The gold occurs mainly in tellurides and sulphides, only a minor proportion existing in the free state. The principal accessory minerals are magnetite, siderite, iron pyrites, and arsenical pyrites.

The tellurides occur as veins, splashes, and disseminated minute crystals throughout the entire mass.

Mount Morgan Lode.—The great ore-body in Mount Morgan mine in Queensland is believed by some to be a huge pyritic lode. In the upper part of the deposit, it consists of siliceous hæmatite or *gossan*, often with a porous, cavernous structure; and in the lower part, of massive pyritic gold-bearing ore. A zone of secondary enrichment of great value was met with in the oxidised zone.

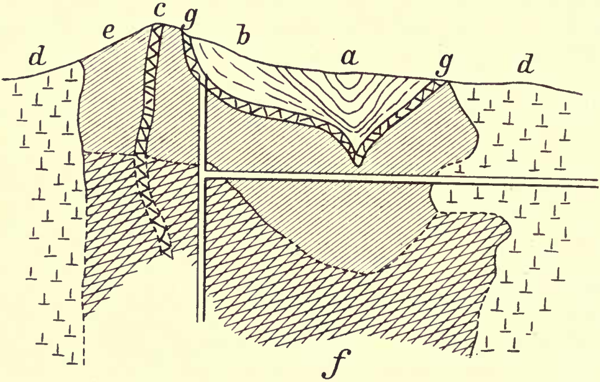

Fig. 35.—Cross-section of Mount Morgan Lode. (After E. J. Dunn.)

(*a* and *b*) Sandstones, etc.	(*e*) Cellular siliceous ore.
(*c*) Dykes.	(*f*) Siliceous sulphides.
(*d*) Igneous rock.	(*g*) Oxidised enriched zone.

The action of sea-water is held by E. J. Dunn[2] to sufficiently account for the secondary oxidised ores, without calling in the aid of thermal springs, as contended by Dr Jack.

The country-rocks are highly metamorphosed strata of Permo-

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[1] G. W. Card, "Notes on the Country Rocks of the Kalgoorlie Goldfield, Western Australia," *Records of the Geol. Survey of N.S.W.*, vol. vi. Part I.

[2] E. J. Dunn, "Mount Morgan Gold Mine," *Proc. Royal Society of Victoria*, 1905.

Carboniferous age, traversed by intrusions of hornblende-granite and dolerite.[1]

The ore-body itself is nearly surrounded by dykes of dolerite, often altered and serpentinised.

The evidence supplied by Dr Jack, Wilkinson, and others seems to indicate that this unique lode is a true fissure-vein, genetically connected with the intrusion of the dolerites. It bears many points of resemblance to the famous copper-contact deposits at Rio Tinto in Spain.

The distinction between contact-deposits and fissure-veins is one of geologic occurrence rather than genetic origin. As will be shown later, the after-actions of a magmatic intrusion may be the genetic cause in the formation of fissure-veins, contact-deposits, or even bed-impregnation.

Tin Lodes of Malaysia.—The tin lodes of the Malay Peninsula, the erosion of which has produced the valuable alluvial placers of the Straits Settlements, are fissure-veins passing from clay slates downward into the basement rock granite.[2]

Gold Veins of Charters Towers.—In this rich goldfield a large number of the veins are enclosed in granite, but some occur in porphyry. The vein-gangue is principally quartz, containing iron pyrites and often pyrrhotite, both of which contain gold.

Copper Lodes of Butte City.—The copper-deposits near Butte City, in the State of Montana, are among the richest in the globe. The country-rock is granite, traversed by dykes of rhyolite trending north and south.[3]

A number of mining companies are operating on a lode or mineralised belt, which can be traced for over 3 miles, in a course running nearly east and west.

The direction of the mineral belt follows the general trend of the fissure planes, which are approximately parallel to each other, uniting in places, running out and uniting again.

Emmons concludes that the granite was fissured by the rhyolite intrusions, which were followed by the usual sequence of eruptive after-actions, including at one stage the circulation of hot ascending solutions. Through the agency of these solutions, the granite became decomposed along the lines of fracture, and the ore-bodies formed by metasomatic interchange.

Much of the ore occurs in thin interlacing veins, some of it impregnating the granite, and some as huge ore-masses.

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[1] C. S. Wilkinson, Notes on a Collection of Rocks and Minerals from Mount Morgan," *Records of Geol. Survey of N.S. W.*, 1891, vol. ii. p. 86.

[2] W. H. Derrick, Notes on Lode Tin Mining in the Malay Peninsula," *Trans. Inst. Min. and Met.*, vol. vii., 1898-1899, p. 12.

[3] S. F. Emmons, "The Copper Resources of the United States," *Trans. Amer. Inst. Min. Eng.*, vol. xix. p. 678.

The oxidised portion carried silver, mainly the chloride, and no copper of any moment, down to a depth of about 400 feet, where a zone of secondary enrichment was met with, containing rich oxysulphides and other secondary ores of copper. Below this zone appeared the normal sulphide ore, which consists principally of chalcopyrite, bornite, and copper glance, containing from 6 to 10 per cent. of copper, and a little silver.[1]

The width of the lodes varies considerably, but on an average may be taken at about 10 feet.

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[1] Douglas, "The Copper Resources of the United States," *Trans. Am. Inst. Min. Eng.*, vol. xix. p. 679.

CHAPTER III.

ORE VEINS—THEIR FILLING, AGE, STRUCTURE, WALL MOVEMENTS, PAY SHOOTS, ETC.

CONTENTS:—Filling of Cavities and Veins—Origin of Vein Cavities—Age of Vein-filling—Width of Lodes—Length—Stroke—Inclination—Depth—Arrangement of Lode Matter—Horses in Veins—Outcrops of Veins—Condition of Metallic Contents—Position of Valuable Contents—Pay Shoots—Gold Bonanzas—Wall Movements—Influence of Country—Productive Zones—Vertical Distribution of Ores—Secondary Enrichment of Veins—Impoverishment of Veins in Depth—Indicator Beds—Paragenesis—Temperatures in Deep Mining—Recording Rock Temperatures—Limits of Deep Mining—Metasomatic Replacement.

Filling of Cavities and Veins.—The precipitation of dissolved matter from circulating underground solutions and gases was, doubtless, in most cases, due to a combination of physical and chemical causes operating in conformity with well-known physical laws.

The problem is one of the most difficult connected with the genesis of ore-bodies, and is made more so by our lack of knowledge of the chemical constitution of the substances held in solution.

It is not uncommon to find a vein containing sulphides of iron, copper, lead, zinc, antimony, and silver, all enclosed in a matrix of quartz.

In many cases there is a symmetrical arrangement of the vein-matter; but in other cases the sulphides are deposited throughout the matrix irregularly, and apparently without order or system, forming masses intimately associated, yet still only mechanically mixed, clearly suggesting that the process of deposition had a nuclear tendency, in consequence of which each ore went to itself, and formed aggregates, both small and great.

Deposition of vein-matter from underground solutions may be effected by one or more of the following causes:—

(*a*) The cooling of solutions charged with dissolved mineral matter.

(*b*) A decrease of pressure.
(*c*) Electro-chemical action.
(*d*) Chemical precipitation.
(*e*) By other contact with other mineralised solutions.
(*f*) By gaseous emanations.
(*g*) By absorption of metals by gelatinous silica, etc.

Origin of Vein Cavities.—The solutions either found the cavities awaiting them, or they formed their own channels by a process of slow progressive replacement of the wall-rock parallel to primary fractures.

If the cavities were pre-existing, they were formed mechanically by forces either (*a*) *internal*, or (*b*) *etxernal* to the rock affected.

In the case of eruptive magmas unequal cooling of the igneous mass would tend to create unequal internal tensions, with the result that fissures of contraction would be formed. Magmas, like the molten charge in a blast furnace, will corrode the walls of their cavern, and the "plucking" action of the rising pasty mass will tend to detach fragments from the roof and sides. Daly[1] concludes that the digestion of solid rock by a magma causes an increase of volume of the magmas, thereby furnishing sufficient energy to fracture the overlying rocks and force the magma itself along planes of weakness.

Sedimentary and older eruptive rocks may be fractured by an igneous intrusion, or by the lateral and tangential stresses created by the secular folding of the crust of the earth. Such forces are external to the rock-mass affected; and if we consider the manner in which they act, we shall find that igneous intrusions play a more important part in the genesis of vein-cavities than the more ponderous secular earth-movements.

Secular movement is extremely slow, seldom exceeding a few inches in a century. The folding which it causes being for the most part of wide structural or tectonic importance, is continental rather than local. When the stress exceeds the elastic limit of the material the resultant effects are faulting and shearing, plication and sharp infolding.

The fracturing which produces open fissures and cavities is chiefly the work of igneous intrusions and volcanic forces. These agencies having made the cavities, also provide the mineralised gases and solutions that corrode and replace the shattered rock and fill the fissures with mineral matter.

Ore-bodies are often formed along joint and fault planes, and at the intersection of joints, simple fractures, and faults. A

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[1] Daly, R. A., "Mechanics of Igneous Intrusion," *Amer. Journ. Sci.* [4], vol. xvi. p. 107, 1904.

typical example of this class of deposit in Bendigo goldfield, Victoria, has been shown by T. A. Rickard.[1]

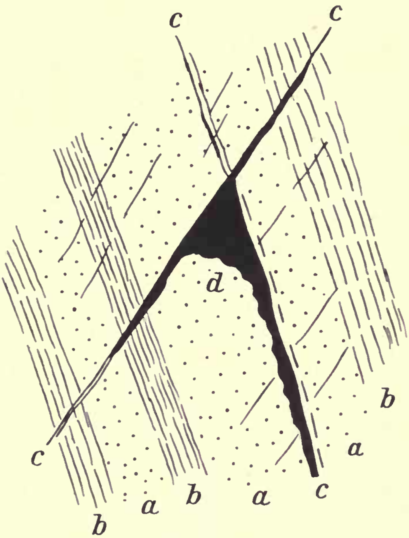

FIG. 36.—Typical Section of Ore Body at Intersection of Fractures. (After T. A. Rickard.)

(*a*) Sandstone. (*b*) Slate. (*cc*) Fractures.
(*d*) Gold-bearing quartz in the form of a *false-saddle reef*.

The sulphide ores of Monte Cristo, in the State of Washington, are stated by Spurr[2] to be replacements of the country-rock tonalite. The ores, which are chiefly galena, blende, chalcopyrite, pyrite, and arseno-pyrite, are concentrated along joint planes and intersections in the manner shown in the next figure.

Age of Vein Filling.—It sometimes happens that the lodes in a district are of different ages, and that the members of one system make an angle with those of another system. When displacement takes place, it is evident that the vein which displaces another vein is younger than the displaced vein.

In the case of large fissures now filled with mineral matter, it is highly improbable that they remained as open chasms without support until they were filled. It is generally believed that in the beginning the fissures were of small size, and gradually

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[1] T. A. Rickard, *Trans. Am. Inst. M.E.*, vol. xx. p. 469.

[2] J. E. Spurr, "Ore Deposits of Monte Cristo, Washington," 22*nd Annual Report United States Geol. Survey*, 1900–1901, Part II. p. 849.

increased in length, depth, and width as the mineral matter accumulated in them to afford the necessary support. In other words, the enlargement of the lode was the work of metasomatic replacement operating upon the rock forming the walls of the original fissure.

It might be expected that if later movement took place, it would tend to follow an old line of fissure rather than initiate a new one, and in support of this view there is internal evidence in many lodes that they have been reopened at different periods.

Portions of the Martha lode at Waihi have been brecciated by wall-movements and re-cemented; and evidences of a similar character are not uncommon elsewhere.

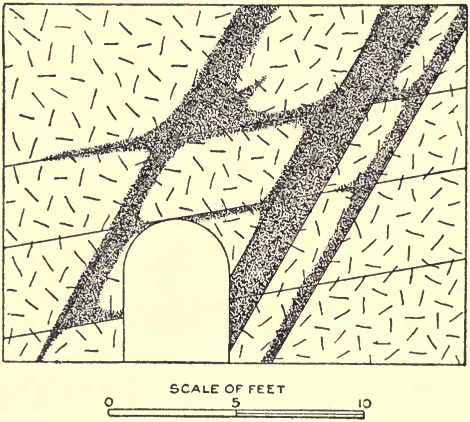

FIG. 37.—Sketch-section of Tunnel and Vein Exposure in Vertical Cliff, Glacier Creek, showing mineralisation along joints by, probably, descending waters. Shaded areas represent impregnation of tonalite with sulphides along joints, sometimes becoming solid ores. (After Spurr.)

Weed,[1] who made a special examination of the copper-veins of Butte, in Montana, states that the veins there are of several ages and systems, and that the older primary quartz-pyrite veins were reopened by later movements, which he correlates with a period of volcanic activity. This reopening, he says, resulted in the deposition of the copper sulpharsenide, enargite, which is now found to be the chief ore of some of the veins.

As a rule the formation of vein-matter took place after the formation of the enclosing rock.

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[1] W. H. Weed, "Ore Deposition and Vein Enrichment by Ascending Hot Waters," *Trans. Am. Inst. M.E.*, vol. xxxiii., 1903.

In many lodes there is evidence that there were several periods of ore-formation. Recent investigation has shown that the age of a lode may be of comparatively late date even in very old rocks.

The metalliferous andesitic rocks in South America, Nevada, Transylvania, and New Zealand were erupted in middle Tertiary times; hence the contained veins must be of later date, probably of older Pliocene age. The majority of veins occurring in clastic rocks are supposed to have been formed in later geological times.

Width of Lodes.—Lodes vary considerably in width both along their course and in depth. The Comstock lode is in parts 200 feet to 300 feet wide, and in others not more than 20 feet. The Premier lode at Te Aroha varies from 20 feet to 60 feet wide, and stands up like the wall of a house along the flanks of the mountain for miles. The Martha lode, at Waihi, varies from 10 to 90 feet wide. The Bohemian Pfahl in a length of 34 miles maintains an average width of 100 feet, but in places widens out to 375 feet, while the Great Pfahl in its course of 92 miles varies from 225 to 370 feet in width.

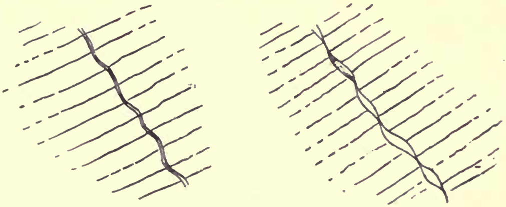

FIG. 38.—Showing Effects of Faulting.
(*a*) Before faulting. (*b*) After faulting.

The variations in width may be due to several causes. The rock may have yielded more at one point than at another during the formation of the fissure.

A fracture that passes through alternating bands of hard and soft rock generally follows a sinuous course; for while the fracture tends to pass through the softer rock in a direction normal to its course, the resistance offered by the hard rock causes it to take the shortest distance through the resisting medium, which will be a course at right angles to the bedding or foliation plane.

When faulting takes place on the walls of such a sinuous fissure, the result is a succession of wide and narrow cavities, as shown in fig. 38.

The Temperance lode in the Nerrena or Little Bendigo goldfield in Victoria is a typical example of an ore-body composed of a string of lozenge-shaped masses. According to W. Bradford,[1] the lode traverses a series of alternating slates and sandstones of Silurian age. In vertical distance, it consists of a succession of wide and narrow parts, the wide parts forming in the slates and the narrow in the harder sandstones, as drawn in the accompanying figure, which, however, does not show any appearance of faulting.

Again, it is possible that erosion, either chemical or mechanical, may have acted in one portion of a fissure more than in another.

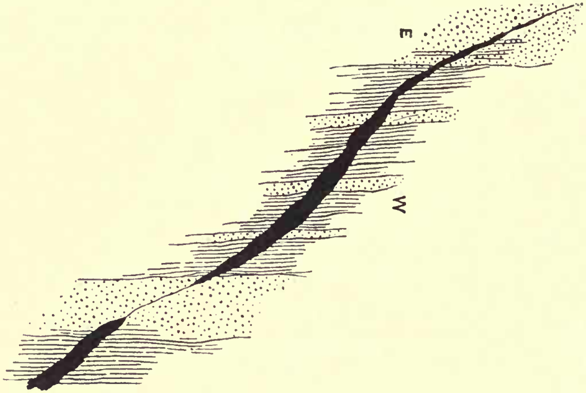

FIG. 39.—Section of Temperance Lode, showing "makes" of quartz in slates. Scale, 1 in. to 40 ft. (After W. Bradford.)

Lodes are generally widest in soft or moderately soft ground, and narrowest in hard rocks such as unaltered granite, andesite, and diorite. In hard rock, a lode will frequently dwindle down to a mere crack or clay parting, and expand to its normal size on entering softer country.

Length of Lodes.—The longest lodes are generally those which are broadest. Of the three great lodes traversing the slopes of the Bavarian Forest the Asch lode is traceable for a distance of 25 miles, the Bohemian Pfahl for 34 miles, and the Great Pfahl for a length of 92 miles.

In Cornwall the average length of a load is about a mile, in Saxony 3 to 4 miles, and in the Harz Mountains 8 to 10

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[1] W. Bradford, *Bulletin No.* 15, *Geol. Survey of Victoria*, Melbourne, 1905, p. 6.

miles. In California the Great Mother lode has been traced for over 70 miles.

In the Hauraki goldfields, in New Zealand, the Tokatea lode can be traced for 3 miles; the Waiotahi lode, 2 miles; the Premier lode, Te Aroha, 4 miles.

Strike or Bearing of Lodes.—In many mining districts the main lodes possess a general bearing. Thus in Cornwall the general strike is E.N.E.-W.S.W., and in the north of England E. and W. In Prussia many of the iron lodes strike N. and S. In the Hauraki goldfields the trend of the most productive lodes is N.N.E.-S.S.W. On the other hand, the lodes in the Freiberg district run in various directions. A change of strike has sometimes an influence in the enrichment of a lode.

In some mining regions there is a great similarity in the contents of the lodes running in the same direction. Thus in Cornwall the E.N.E lodes yield tin, copper, and a little lead, while the N.S. lodes yield clay and lead. But the exceptions are too many to allow a safe generalisation to be made.

Inclination of Lodes.—The dip of a lode may vary as it descends in depth, or may vary at different points along its course. The dip is spoken of as flat or steep. It is always at right angles to the strike.

The Samson lode at Andreasberg, the Talisman lode at Karangahake, and the Empire lode in the Waihi mine in New Zealand, dip in opposite directions in different parts of their course.

Moissenet, in his classical work on the *Lodes of Cornwall*, fully endorses the generalisations of Henwood relating to the influence of inclination, strike, and character of country upon the contents of the lodes of that country. With respect to these he formulated the following laws:—

(1) Those parts of the lode whose inclination is most nearly vertical are always the most productive.

(2) In the rich parts the lode is enclosed in country of moderate hardness.

(3) The "courses" or "shoots" generally dip in the same direction as the "country," and very often also the groups of bunches contained in the same lode.

(4) The bearing of the rich parts is generally that of the stratigraphical system with which the initial fracture of the lode in the region under observation is connected.

These laws hold good for the lodes of Cornwall. It is doubtful if they can be safely applied in other mining regions, and each of them has been disproved in different places.

Take the first law. The richest bonanzas in the Thames goldfield were found in the Caledonia and Cambria reefs, in places where the angle of dip was under 30°. Both above and below the bonanzas the dip was about 45°.

Depth of Lodes.—With the exception of gash-veins, which are wedge-shaped openings from the surface the depth which veins may attain has not yet found a limit.

The greatest depth to which a lode has been followed downwards is at Przibram, in Bohemia, where one of the mines has reached a depth of nearly 4000 feet, and is still being deepened. The gold-mines of Victoria and the copper-mines at Lake Superior have reached depths ranging from 2000 feet to 5000 feet.

It seems likely that fissure-veins will descend to a greater depth than mining operations can follow them.

Arrangement of Lode Matter.—The gangue or matrix of most veins is quartz. The most notable exception is lead, which often occurs in veins of calcite or fluor-spar.

The quartz may be flinty or chalcedonic, finely or coarsely crystalline. It may be banded, ribbon-like, concentric, brecciated, compact, vuggy, granular, disseminated, or in loose sugary grains. The arrangement of the lode-matter should always be observed, since the structure and arrangement will almost always tell us something about its history.

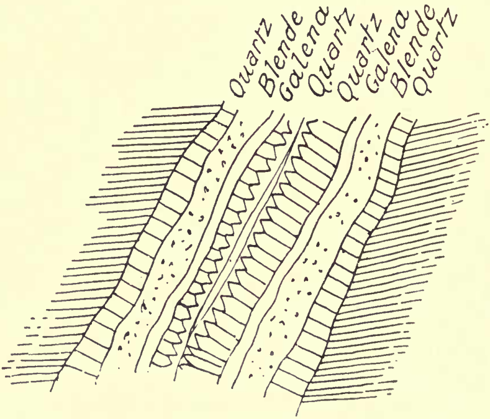

FIG. 40.—Showing Ribbon Structure of Vein Matter.

In lodes of the base metals the contents are sometimes arranged in bands or layers parallel to the walls, the minerals and ores on one wall being represented by corresponding layers on the other wall.

When the bands are made up of crystalline aggregates, the individual crystals are arranged with their longer axis at right angles to the plane of the walls. This arrangement is sometimes termed *comb-structure.*

Such symmetrical arrangement is, however, rare. Generally the layers are thicker on one wall than on the other; and frequently a layer of ore on one wall has no corresponding representative on the other.

Lodes filled with chalcedonic quartz like the upper part of the Martha lode at Waihi, or with sugary quartz like the Comstock lode, exhibit little or no symmetrical arrangement of mineral contents.

In some cases the vein-filling consists of broken rock, wholly or partly filling the vein-cavity; in others, a band of friction-breccia occupies one wall.

The Cambria lode at Thames has a band of breccia on the hanging-wall varying from 2 to 4 feet thick. The breccia is not co-extensive with the vein-matter, but occurs in flat lenticular layers.

Horses in Veins.—A mass of country-rock embedded in the matrix of a lode, and more or less completely detached from the walls, is termed when large a *horse*, and when small a *floater*, or *rider*.

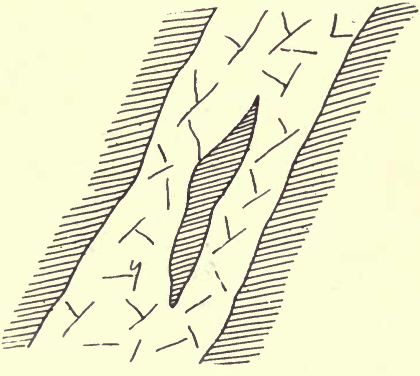

FIG. 41.—Horse or Floater in a Vein.

A horse is a slice of rock that has become detached from the hanging-wall while the siliceous filling was still in a gelatinous condition.

In Cornwall and elsewhere experience has shown that the occurrence of a horse is often attended with an enrichment of the contents of the lode, a circumstance which doubtless originated the Cornish aphorism, *A horse pays for itself*, meaning that the increased richness of the lode more than compensates the extra labour and expense of working caused by the appearance of the horse.

In the steeply inclined gold-bearing veins of the Thames horses of rock were often met with, and in almost every instance they caused local enrichment, the increased values being generally confined to one split or branch of the lode.

Investigation showed that this enrichment was not due to a concentration of the values into one branch, but to an actual increase in the mean values previously ruling in the main lode.

Outcrops of Veins.—Professor Van Hise[1] distinguishes the different zones of rock-alteration by a nomenclature suggested by the biological terms used to designate the somewhat parallel changes in animal life. His subdivisions are as follows:

1. *Zone of Katamorphism.*
    - *a.* Belt of weathering.
    - *b.* Belt of cementation.

2. *Zone of Anamorphism.*

The Katamorphic zone is that in which complex compounds are broken down and altered into simple compounds. In other words it is the zone of oxidation.

In the Anamorphic zone the alteration of rock masses results in the production or building up of complex compounds from simple compounds.

The belt of weathering extends down from the surface to ground water-level, the belt of cementation from ground water-level to the zone of Anamorphism.

Chemical action is very active in the zone of Katamorphism, and is in most cases accomplished by descending solutions. The changes effected in this zone are: (a) *oxidation*, (b) *hydration*, and (c) *carbonation*.

By long-continued exposure to atmospheric agencies and the action of descending meteoric waters, the outcrops of iron, copper, and silver sulphide lodes are often oxidised and so altered by removal and replacement as to bear little resemblance to the unaltered vein-matter which will generally be found at a greater depth.

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[1] Chas. Richard Van Hise, "A Treatise on Metamorphism," *U.S. Geol. Survey.* Washington, 1904.

The iron sulphides are oxidised first to sulphates and then to oxides, while the copper is removed by water in the form of soluble sulphates, or is oxidised to carbonates, which stain the rocks green and blue. Silver sulphides are altered to the chloride near the surface, or the dissolved metallic contents are found concentrated at or below water-level.

In many sulphide lodes iron is the predominating constituent, and its oxidation generally results in the outcrop assuming a porous, honey-combed appearance, the removal of the sulphides leaving cavities which are only partially filled with oxide. The ferruginous solution flowing from the outcrop stains and discolours the surrounding rocks and soil.

Such ironstone outcrops are known as *gossan* in Cornwall, *iron-hat* in Germany, and *ironstone blows* in Australia.

The nature of the gossan varies with the character of the original sulphide ore-body. If much quartz is present, the outcrop is cavernous and cindery, red or brown-coloured ; but if the ore-body is composed mainly of iron pyrites, the gossan will consist of ochre and brown hæmatite, often in botryoidal and stalactitic forms.

The oxidation and leaching of lode-matter has often proceeded to a depth of 500 feet below the surface outcrop, in some cases far below the present water-level. Sometimes there is a sharp line of demarcation between the oxidised and unaltered portions of a lode, but more often the passage is gradual, the suphides at first making their appearance in detached nodules, bunches, or small lenticular masses, which gradually become more plentiful with increasing depth.

A gossan is always an indication of a lode below, and, for this reason, forms a valuable guide to the prospector.

Gossan outcrops should be carefully sampled and assayed, as they may contain valuable minerals the presence of which could not be detected by panning.

The valuable gold and silver lodes of the Hauraki goldfields give little or no indication of their value by crushing and panning. The gold exists in such a finely divided state that a *colour* is rarely seen in the ore, and the value can only be ascertained by careful sampling and fire-assay.

The rich, unoxidised sulpho-telluride ores of Western Australia possess no physical feature of a striking character to indicate their great value, and when tested by the prospector's ready method of rough crushing and panning appear valueless.

Each mineral possesses certain characteristic indications peculiar to itself, and must be considered separately. Thus an iridescent film or layer of oil on a pool of water, or an emanation of carburetted hydrogen, may direct attention to the existence of petroleum in the vicinity.

Brine springs point to deposits of salt, and chalybeate springs to iron, though not necessarily of commercial value. Puffs of steam or the smell of sulphuretted hydrogen in a volcanic region may point to the existence of sulphur. For instance, at Rotorua and White Island, in New Zealand, extensive deposits of sulphur are found around the numerous fumaroles, both active and extinct, and at both places the odour of sulphuretted hydrogen is plainly perceptible long before the deposits are reached.

Condition of Metallic Contents of Veins.—Gold occurs in the native or uncombined form, but at Cripple Creek and Kalgoorlie much of it exists combined with tellurium.

In the portions of the veins that have been subject to the oxidising influences of surface waters, gold occurs in a free-milling condition—that is to say, it unites readily with mercury to form amalgam, being free from tellurium and base sulphides.[1]

Below the reach of oxidising influences, the gold is often associated with metallic sulphides, generally iron pyrites, in which it often exists entangled in an excessively fine condition, so fine that when the recovery of the gold is attempted by chemical dissolution with aqueous solutions of potassium cyanide, sufficient extractions can only be obtained when the sulphides have been ground extremely fine, so as to enable each particle of gold to come in contact with the solvent.

The Waihi bullion extracted by the cyanide process from the Martha Hill lodes contains from one-quarter to one-third per cent. of selenium, and on some occasions as much as 1 per cent., but no trace of this rare metal can be detected in the ore itself by chemical tests.

Silver ore is generally converted in the upper part of lodes into the free-milling chloride, which, below water-level, is displaced by sulphides. Native silver, bromides, and iodide often accompany the chloride.

The sulphides of copper lodes are converted in the upper portion of the vein into sooty secondary sulphides, oxides and carbonates, often of great richness. At the outcrop, the copper contents have been oxidised and removed, leaving rusty brown caps of ironstone more or less quartzose and porous.

Position of Valuable Contents.—Sometimes the metallic contents of a vein are evenly distributed throughout the gangue.

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[1] It must always be remembered that gold may be free and yet exist in particles so fine that there is considerable mechanical difficulty in bringing the particles in contact with the mercury so as to obtain an adequate recovery of the precious metal in the form of amalgam.

Generally, however, they occur more at one point than another, existing in masses known as *bunches*, *nests*, *chimney-shoots*, *pipes*, *courses*, *patches*, *pockets* or *bonanzas*.

Only in rare cases do veins carry payable values for their whole length, or, in their full width, from wall to wall. Hence a pay-shoot may be defined as that portion of an ore-body which is commercially valuable.

The majority of pay-shoots dip in the same direction as the lodes, but generally at a flatter or steeper angle, more often the latter. Hence the pay-shoot is not always co-extensive with the lode, and often passes out in depth.

Narrow, vertical, or nearly vertical, payable portions of a vein are termed *chimneys*, or *pipes*; and flat, nearly horizontal portions, *courses* or *benches*.

The causes which have brought about the unequal distribution of the valuable contents of a lode in shoots, pockets, or courses, are either not known, or but imperfectly understood. It has however, been noted that gold-bearing veins become enriched at the intersection of indicator beds and flinty cross-courses; and that veins traversing propylitised andesite become enriched or impoverished with a slight change in the character of the andesite. The connection of circumstances in these cases is manifest, but the explanation is difficult.

Pay Shoots.—These may be of any shape and size. They may dip in the same direction as the lode, and yet be inclined in linear extension.

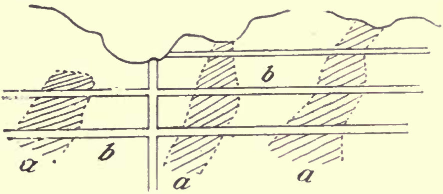

Fig. 42.—Longitudinal Section of Vein, showing succession of pay-shoots. (*a*) Pay-shoots. (*b*) Poor ground.

Pay-shoots vary from a few yards to thousands of feet in length, and sometimes two or more shoots occur in the course of a vein, separated by longer or shorter stretches of poor ore, as shown in fig. 42.

The dip and pitch of a pay-shoot should always be carefully noted so as to obtain a clue as to the probable position of the valuable ore at different levels.

In many veins, the payable material does not always extend from wall to wall. The values sometimes lie on the foot-wall, and sometimes on the hanging-wall, or in a band of ore situated near the centre of the vein, or in a thin streak which crosses the vein obliquely, passing from wall to wall.

The extent of the payable ore can always be ascertained by systematic sampling, provided a careful record is made of the values on the mine-assay plan.

Gold Bonanzas.—The rich bonanzas for which the Thames and Coromandel goldfields are celebrated occur in the richer zones. They are places where the quartz contains coarse daubs or masses of gold, forming what is locally called *picked* or *specimen* stone, which is frequently found to yield as much as six ounces of gold to the pound of stone.

The Hauraki bonanza varied from 100 to 120 feet wide, and extended to the 300 feet level from a point about 60 feet from the surface. It pitched slightly to the north-east, and was cut off by a fault about 30 feet from Bunker's boundary.

In these goldfields the pay-shoots commonly occur along the line of intersection of a cross-vein or *flinty*, which is a thin indicator vein consisting of dense flinty quartz, generally pyritic.

Wall Movements of Veins.—Faulting has taken place along the course of most large veins. In some cases the faulting took place before the filling of the fissure, and, in other cases, when the veins were partially formed but not consolidated.

When the faulting took place after the consolidation of the lode-matter, the result was the production by attrition of a layer of pug or clay on the wall on which the movement took place. On the side on which the pug occurs all the small veins and droppers are thus cut off or displaced; and it is for this reason that branching veins are only found on the side on which no movement has taken place.

In some classes of country faulting along the course of a vein has caused the formation of friction-breccias on one or both walls. Such breccias seldom exceed a few feet in thickness, and mostly form lenticular-shaped masses of varying length and depth.

In hard country, movement on the walls has often produced slicken-sides; and in some cases the *flucan* or clay partings between the vein-matter and walls has assumed a flaky or platy character through the stress of lateral pressure.

Influence of Country-Rock.—Observation in many countries has shown that the valuable contents of a vein are often influenced by the character of the country-rock traversed by the vein. It is also recognised that certain rocks favour the occurrence of particular ores and minerals. Thus tin has a preference for granite rocks; while copper is usually associated with serpentines, diorites, chloritic schists, and slates. Limestone, more especially when dolomitic, yields lead in many countries. In Chili and Austrialia it yields lead and silver; in Belgium, zinc; and in England, iron and lead.

A change in the rock often causes a change in the richness of a vein.

In the Hauraki goldfields and in Transylvania, the veins are productive in altered andesite, but barren in the breccias and tuffs. At Cripple Creek, the veins are most productive in andesitic breccias.

In Yorkshire, the lead-veins are good in limestone, not so good in grit and limestone, worse in shale and limestone, and worst in shale.

Sandberger strongly urged the influence of country-rock upon the contents of veins; and his researches have been supplemented and verified in later years by those of many accomplished American geologists, whose opportunities for observation in the field have been wide and varied.

In the Hauraki goldfields, the author found that the productive character of the veins was strongly influenced by the containing rocks. The results of his researches in this region during a period of twelve years may be summarised as follows:—

(*a*) The rock which has yielded the largest quantity of gold is a moderately hard yellowish-gray altered andesite, the "kindly sandstone" of the miners.

(*b*) The most favourable country is not too soft, nor yet too hard, being shooting ground, requiring two or three shots to the shift.

(*c*) In very hard country-rock, the veins are generally smaller than in soft rock; and when a vein passes into hard andesite, it invariably becomes smaller, and often thins out to a mere clay-parting or "clay-head."

(*d*) The veins in the hard rock have not proved so remunerative as those in the miner's "kindly sandstone," and this is due not so much to their leanness as to their smaller size and the greater cost of working them.

(*e*) When a vein passes from altered andesite into a tuff or breccia, it invariably becomes barren, or too low grade to be payable. This is true in all parts of the Hauraki Peninsula; and experience has shown that the veins which exist in tuffs or breccias are often superficial in character, and seldom reliable as gold-producers, although some have been found to contain small shoots of a payable nature.[1]

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[1] J. Park, "The Geology and Veins of Hauraki Goldfields, N.Z.," *Trans. N.Z. Inst. Mining Engineers*, vol. i. 1897, p. 46.

Productive Zones.—The mining operations of the past thirty-five years in the Hauraki area have shown that in the different belts of altered andesite there are certain zones which are more productive than others. Even in the case of several parallel veins, it has been found that all become enriched on entering the favourable zone, thereby affording a graphic illustration of the miner's aphorism, *ore-against-ore.*

There are several such zones in the Moanataiari end of the Thames field, the best-known being those at Kuranui Hill and Point Russell. The latter affords, perhaps, the most graphic illustration of the influence of favourable country. At that place the Moanataiari mine is traversed by four large parallel lodes—namely, the Dauntless, Reuben Parr, Golden Age, and Waiotahi, all pursuing a N.N.E.-S.S.W. course.

On entering the productive zone, the ore changes from excessively low grade to high grade, this character being maintained till the zone is passed through. This zone crosses the course of the lodes nearly at right angles.[1]

The following diagram shows the general distribution of the productive zones on this field:—

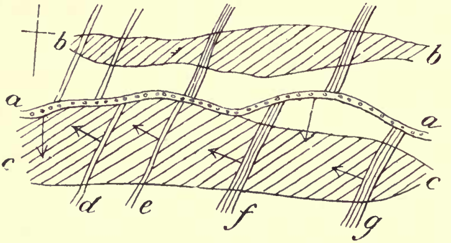

Fig. 43.—Plan of Northern Portion of Thames Goldfield, N.Z.

(*aa*) Great Moanataiari fault.
(*bb*) Point Russell productive zone.
(*cc*) Kuranui productive zone of altered andesite.
(*d*) Shotover vein.
(*e*) No. 9 vein.
(*f*) Caledonia vein.
(*g*) Waiotahi vein.

Mining operations disclosed the circumstance that the rich zones were not only limited in width but also in depth. Further, they were found to dip to the southward, that is, in the opposite direction to the dip of the veins.

The cross-section along the line joining *cc* shows the relation of the parallel veins to the Kuranui productive zone.

The shaded portion represents the Kuranui productive zone of altered andesite.

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[1] J. Park, *loc. cit.*, p. 50.

The gold occurred in the productive zone in shoots and rich bonanzas, which in almost every case were found along the line of intersection of a small cross-vein, locally termed a *leader*.

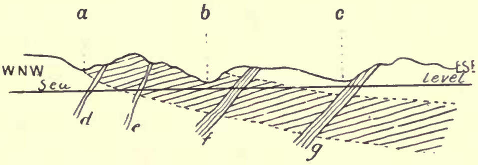

FIG. 44.—Section along Northern Foreshore, Thames Goldfield.

(*a*) Shotover Creek.
(*b*) Moanataiari Creek.
(*c*) Waiotahi Creek.
(*d*) Shotover vein.
(*e*) No. 9 vein.
(*f*) Caledonia vein.
(*g*) Cambria vein.

At the Kuranui end of the field, the shoots occurred near the surface, but going southward they were found at increasing depths. In the Queen of Beauty shaft, in the south end of the goldfield, the productive zone was followed to a depth of nearly 1000 feet below sea-level.

Vertical Distribution of Ores in Depth.—Mining operations in the United States, England, and elsewhere have shown that while in many veins the metallic sulphides are intimately mixed without any definite arrangement, in other veins, particularly those of lead, zinc, and iron, there is an orderly distribution in horizontal zones which succeed each other in a vertical direction—that is, there are certain horizontal zones, each of which is characterised by a dominant sulphide.

This arrangement of the metallic contents of a vein, in more or less horizontal zones, was noticed in Cornwall many years ago; and no better example could be found than that presented by the celebrated Dolcoath mine, which commenced as a tin-mine, at a lower depth yielded nothing but copper, and again, below that, tin.

In the great lead- and zinc-mining region of Ozark, in the Lower Mississippi Valley, the vertical distribution of the ores, according to Bain, is as follows:—

(1) Oxidised zinc and lead ores, with galena.
(2) Blende, with a little galena.
(3) Iron sulphides predominate and increase with depth.[1]

Spurr, in his report on Monte Cristo mining district, in Washington, states that the quartz, pyrite, chalcopyrite, pyr-

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[1] H. F. Bain, *United States Geol. Survey Twenty-Second Annual Report*, Part II. p. 161.

rhotite, blende, galena, realgar, stibnite, and calcite show a marked tendency to aggregate themselves in horizontal zones in the order named.[1]

Rickard mentions the orderly distribution of ores in Colorado.[2] Weed states that in the Castle Mountain district, in Montana, the order appears to be galena on top, passing into highly zinciferous ores below, and those into low-grade pyrite.[3]

At Broken Hill lead and silver mines, in New South Wales, the general distribution of ores in vertical depth has been as follows:—

(*a*) Oxidised ores of lead and silver.
(*b*) Galena, with blende.
(*c*) Blende, with galena.

Weed,[4] in a paper on "Ore Deposition and Vein Enrichment by Ascending Hot Waters," appears to support the hypothesis which assumes that the distribution of ores in horizontal zones is the result of primary concentration by ascending hot solutions. This view has much to commend it.

The eruption of igneous magmas is often succeeded by intense solfataric action, of which notable examples are found in the Yellowstone Park, in the United States, and in the volcanic region of the North Island of New Zealand.

The ascending waters slowly circulating in contact with heated rocks below become superheated, and in their upward course dissolve various substances, which they carry with them along the line of least resistance, that is, towards the hot spring pipe or vent.

Many substances, insoluble in normal conditions, are rendered easily soluble in the presence of heat and pressure. The underground waters will, therefore, possess their greatest solvent power where the greatest heat and pressure prevail, which will naturally be at the greatest depth.

With loss of heat and pressure, the least soluble substances will be precipitated—that is, those substances whose dissolution was effected under extreme heat and pressure.

As the waters ascend they will continue to lose heat and be relieved of pressure, with the result that the dissolved minerals will be precipitated in the inverse order of their solubility.

When the hot waters reach the surface, the only substances in solution in most cases will be the extremely soluble alkaline

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[1] J. H. Spurr, *loc. cit.*, p. 841.
[2] J. A. Rickard, *Trans. Inst. Min. and Met.*, London, vol. vi., 1899, p. 196.
[3] Weed and Pirsson, *Bulletin* 139, *U.S. Geol. Survey*, 1896.
[4] W. H. Weed, *Trans. Amer. Inst. M.E.*, vol. xxxiii., 1903.

sulphates, carbonates, and silicates. In support of this it may be mentioned that hot springs commonly deposit silica and rarely metallic sulphides at the surface.

In many lodes it is a common feature to find sulphides, or their oxidised products, at the surface, but in such cases it is always well to bear in mind that veins which outcrop at the surface may have been truncated to a greater or less degree by denudation.

The obvious inference to be drawn from this process of vein-filling is that impoverishment of the ore must take place in all veins at great depths, due to the migration of the valuable minerals from the *zone of dissolution* below to the *zone of precipitation* above.

Secondary Enrichment of Veins.—It has been noted in all parts of the globe that rich masses of ore often occur in the oxidised portion of the ore-body, or in that portion lying near water-level.

Microscopic investigation has shown that these rich masses are not of primary but of secondary origin. Their genesis is supposed to be due to the migration of the valuable metallic contents from the higher part of the vein to the lower part of the oxidised zone by the agency of meteoric waters.

In some cases, the processes of dissolution, migration, and redeposition may have taken place over and over again, each cycle resulting in an increasing degree of concentration.

The veins in which secondary enrichment are most often seen are those of gold, silver, copper, lead, and zinc.

Gold ores, in the *zone of weathering*, are often augmented in value by the long-continued disintegration of the vein and the enclosing rock, thus permitting the gold set free from its matrix to concentrate at the outcrop.

Extensive areas of the Australian continent have been subject to sub-aerial denudation since the close of the Palæozoic period, and it is doubtless due to this cause that so many notable examples of *mechanical enrichment* of gold-bearing veins have been found in Victoria and Western Australia.

The migration of gold, copper, silver, lead, and zinc from the upper to the lower parts of the veins is affected by descending surface waters in the zone of vadose circulation. The processes involved in the migration are (*a*) chemical dissolution, and (*b*) electro-chemical deposition.

Chemical processes may operate in various ways to cause secondary enrichment, as follows :—

(1) By the removal of worthless metals, thereby leaving the valuable contents in a purer form.

(2) By removal of worthless metals and their replacements by valuable metals removed from a higher part of the vein.

(3) By deposition of valuable metals on primary sulphides, in those portions of the vein subject to the influence of circulating surface waters. In this case, the primary sulphides may form the nuclei for the deposit of the secondary sulphides.

Manifestly the first operation in the process of secondary enrichment is the chemical weathering and oxidation of the metallic contents of the vein in the Katamorphic zone.

The oxidation of base sulphides can be seen in operation every day. In a mass of mixed sulphides of iron, copper, zinc, and galena, the iron will be the first to be affected from its affinity for oxygen.

Iron pyrites is decomposed and forms ferrous sulphate, which is changed into $Fe(OH)_3$, $Fe_2(SO_4)_2$, and H_2SO_4. The H_2SO_4 attacks more iron sulphide and forms ferrous sulphate, liberating H_2S, which at once combines with free oxygen to form H_2SO_4.

The ferrous sulphate changes to the ferric sulphate, which attacks gold and sulphides of copper, lead, zinc, and silver. The process of dissolution must necessarily be slow, on account of the extreme dilution of the solutions.

For many years it was believed that the only secondary enrichment that could take place was the formation of rich bonanzas of carbonate ores and chloride of silver, in the zone above water-level. But careful investigation in later years has shown that primary sulphides have been enriched by the deposition of secondary sulphides even in places below present water-level.

It was proved experimentally by Skey[1] in 1870, and confirmed by Liversidge[2] in 1893, that gold is more readily precipitated from its solutions by metallic sulphides than by organic matter. Furthermore, Skey showed that sulphides of the base metals were readily precipitated from alkaline sulphide solutions in a solid coherent form in the presence of iron pyrites, galena, blende, stibnite, etc.

The descending acid solutions formed in the zone of oxidation will attack the constituents of the rocks through which they percolate with the production of alkaline silicates and sulphides.

Gold dissolved by ferric sulphate would be also carried down and deposited as leaf, scale, or wire gold in cracks in sulphide ore, thereby causing local enrichment.

It is maintained by some writers that secondary sulphides have

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[1] W. Skey, *Trans. New Zealand Inst.*, vol. iii., 1870, p. 226.

[2] Professor Liversidge, *Proc. Roy. Soc. New South Wales*, vol. xxvii., 1893, p. 287.

been formed below water-level. The evidence on this question is not quite conclusive. In some cases changes of water-level may have taken place since the secondary sulphides were deposited.

The researches of Emmons,[1] Weed,[2] and others have thrown much light on the secondary enrichment of vein-deposits, but much still remains to be done before safe generalisations can be formed.

Some veins, through movement of the walls, have been shattered to some extent and re-cemented by mineralised waters. Such waters ascending through the crushed vein-matter would deposit their metallic contents as sulphides through the reaction of primary sulphides contained in the ore.

In this way, a secondary concentration of primary sulphides may be effected by ascending waters.

The Absorption of Metals by Clays in Relation to Secondary Enrichment.—It often happens that the ore in the zone of secondary enrichment is associated with, or contained in, a matrix consisting of clay or other finely divided mineral matter. Of this there are no more characteristic examples than the Kaolin silver ores of Broken Hill and the talcose gold ores of Kalgoorlie.

Clay and clayey matter are the natural products of the alteration of rocks and ores in the zone of Katamorphism. Their presence calls for no comment; but the frequent occurrence of rich ores in a clayey matrix in certain lodes has led to much speculation as to the relation existing between the clay and its metallic contents.

It has been suggested by some writers that the association is not accidental nor the result of paragenesis, but due to some absorptive quality of the clay. That clay and finely divided matter possess the property of absorbing or extracting metals from their aqueous solutions has long been known, and with this knowledge in mind it has been contended that the clayey matter acting as a porous filter in the lower part of the zone of oxidation, that is in the belt of cementation, has absorbed the metals from the descending solutions, thereby effecting a concentration of the valuable contents.

There is much to be said in favour of this view, but it has still to be determined whether clayey matter and certain porous substances are primary, or merely contributing causes in the formation of zones of secondary enrichment.

Walter Harvey Weed,[3] early in 1905, described some experi-

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[1] S. F. Emmons, *Trans. Am. Inst. M.E.*, vol. xxx., 1900.

[2] W. H. Weed, *Bull. Geol. Soc. Am.*, vol. xi., 1900, p. 179; and *Trans. Am. Inst. M.E.*, vol. xx., 1900.

[3] W. H. Weed, "Absorption in Ore Deposition," *The Engineering and Mining Jour.* New York, 23rd Feb. 1905.

ments on the absorptive property of clays, etc., made by himself and others in the laboratory of the United States Geological Survey in Washington. The results confirmed the researches of W. Skey made in 1869, and of E. Kohler[1] in 1903, who found that clays and porous substances, such as gelatinous silica, carbonaceous and colloidal matter, possess the power of extracting metals from their dilute aqueous solutions.

In 1869, Skey[2] proved experimentally that finely pulverised massive quartz, rock crystal, and silica possess the power of extracting the oxide of iron from its acetate solution. He also found that prepared silica especially manifests this property if ignited at a low temperature, and besides takes oxides of copper and chromium from their acetate solutions. The more finely divided the silica the more apparent is the absorption.

In 1871, he found that when a weak ammoniacal solution of copper containing a little caustic potash is poured upon a filter of Swedish paper (cellulose), the liquid which passes through the paper is quite or nearly colourless, and the filter is found to have retained all, or nearly all, of the copper of such solution.[3]

In 1874, the same chemist showed that clay possesses the property of absorbing and fixing natural petroleum in such a way as to form a substance resembling natural oil-shale, the oil being chemically combined with the clay.[4]

Skey's discovery that gelatinous silica and porous substances possess the property of absorbing metals from their solutions has an important bearing upon the chemistry of ore-deposition in veins and in secondary enrichment.

Impoverishment of Veins in Depth.—T. A. Rickard, when discussing Professor Posepny's classic paper on "The Genesis of Ore Deposits," states that the general non-persistence of ore in depth is a fact capable of proof.[5] He contends that since heat and pressure are the two great factors which increase the solubility of mineral substances, the deep region will favour solution the most, while the shallow zone will favour precipitation, owing to the decrease of heat and pressure.

There is much in favour of this contention. Progressive poverty

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[1] E. Kohler, *Zeitschrift für praktische Geologie*, 1903, p. 49.

[2] W. Skey, "On the Absorptive Properties of Silica and its direct Hydration in contact with Water," *Trans. New Zealand Inst.*, Wellington, N.Z., 1869, vol. ii. p. 151.

[3] W. Skey, "Absorption of Copper from its Ammoniacal Solution by Cellulose in presence of Caustic Potash," *Trans. New Zealand Inst.*, vol. iv., p. 332, 1871.

[4] W. Skey, "Notes on the Formation and Constitution of Torbanite and similar Minerals," *Trans. New Zealand Inst.*, vol. vii. p. 387, 1874.

[5] T. A. Rickard, "Genesis of Ore Deposits," *Discussion*, p. 190.

in depth below a certain depth must be the natural corollary of the general law governing the orderly distribution of ores in horizontal zones, through the agency of ascending waters.

In some cases, impoverishment in depth is determined by the prevailing geological conditions. Ore-veins which are confined to a single overlying formation often die out or become exhausted on reaching the underlying rock.

A notable example of this is afforded by the hydro-thermal veins of the Thames, Tapu, Coromandel, and Kuaotunu mining districts, in the Hauraki mining region of New Zealand, where the gold-bearing veins are contained in altered andesites, which rest on a highly eroded surface of Lower Mesozoic shales, greywacke, and adinole.

Mining operations have in all cases shown that when the veins which occur near the borders of the andesite flows reach the basement rock, they die out completely, or end in small strings, which soon disappear in depth.

The principle of secondary enrichment precludes the continuance of the enriched portion of the vein downward in vertical distance.

When the values of secondary enrichment are added to ore already of a payable quality, the result is a rich shoot or bonanza; but when, as often happens, the secondary values are added to lean ore, then the net result is to render the lean ore just payable. Below the zone of enrichment, the lean ore will be unprofitable.

Thus secondary enrichment is a concentration of values in the oxidised or Katamorphic zone due to the tranference of the valuable contents from a higher to a lower level by the flow of meteoric waters. Only in rare cases will primary sulphides be enriched by this agency.

The Mining Commissioners[1] of Victoria, including the late Professor M'Coy and Mr Alfred Selwyn, the State geologist, reported in 1857 that experience in every country had proved that the yield of gold decreased with the depth after a certain small limit was reached.

The conclusion of the Commissioners[1] was in unison with the opinion already expressed by Sir Roderick Murchison in the first edition of his *Siluria*. This distinguished geologist,[2] as the result of further knowledge, was induced to materially modify his view, particularly, he tells us, as respects the colony of Victoria; but he still adhered to the belief that in general gold veins diminish in value as they descend.[3]

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[1] *Report to Surveyor-General and Chief Secretary on the Mining Resources of the Colony of Victoria*, 1856-57.

[2] Sir Roderick Impey Murchison, *Siluria*, third edition, 1859, p. 494.

[3] *Loc. cit.*, p. 496.

The discovery of payable gold in a saddle-reef in the New Chum Railway Mine at Bendigo, at a depth of 4156 feet, in March 1905, proves that the limit in depth assumed by Murchison must be extended to a depth probably not under 5000 feet.

Indicator Beds.—It is now generally recognised that a vein may become enriched or impoverished in passing from one kind of rock to another. Thus lead veins, which are productive in limestone, are often poor in sandstone or shale; and gold veins, payable in andesite, are often barren in tuffs or breccias.

There are some well-known cases where this influence is exhibited in a special and notable manner. In Kongsberg, in Norway, the prevailing rocks are gneiss and crystalline schists. Certain bands or zones of the latter are impregnated with finely divided sulphides of iron, copper, zinc, and occasionally ores of lead, nickel, cobalt, and silver.

These mineralised bands, locally known as fahlbands, conform to the strike and dip of the enclosing gneiss and schist.

The country-rock and fahlbands are intersected by silver-bearing veins, and it is notorious that these veins are only productive where they traverse the fahlbands.

The indicator-beds of Ballarat, in Victoria, have exercised a remarkable influence upon the distribution of the gold in the veins of that area.

The country-rocks are Silurian slates and sandstones, which are generally tilted at high angles, and often approach the vertical position. They are interbedded with certain thin seams of black carbonaceous shale or slate, to which the name *indicators* is locally applied, from the circumstance that wherever a quartz-vein crosses one of these shale-seams, it uniformly becomes richer along the plane of intersection.

The most persistent of the shale-seams, known as *The Indicator*, is described by E. Lidgey[1] as "a narrow bed of dark slate, usually showing cleavage planes, and containing a large percentage of pyrite, distributed irregularly through it." It varies from a mere sheet to an inch thick, and can be traced for a distance of 7 or 8 miles. It is nearly vertical, and is intersected by a series of nearly horizontal quartz-seams, which are commonly enriched at, or in, the vicinity of the indicator.[2]

Dr Jack, in his report on Gympie goldfield, in Queensland, states that the veins are richest in certain bands of black shale;

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[1] E. Lidgey, *Report on the Ballarat East Goldfield.*

[2] T. A. Rickard, "The Indicator Vein, Ballarat, Australia," *Trans. American Inst. M.E.*, vol. xxx., 1901, p. 1094. This paper contains an interesting summary of the available data relating to the indicators,

and so well is this influence known to the miners that it has, he says, determined the system of mining on the field.[1]

The gold veins in the south end of the Thames goldfield, in New Zealand, traverse altered andesites. They consist of gray-coloured crystalline quartz, but experience has shown that they are only productive where they are intersected by veins locally termed *flinties.*[2]

These flinties are thin veins of close-grained chalcedonic quartz of a gray or brown colour. They usually contain a small proportion of finely disseminated pyrites.

Von Cotta states that the veins near Freiberg are enclosed in mica-schist, which contains an irregular bed of black graphitic schist. The veins, he says, are productive in the black schist, and poor in the mica-schist.[3]

The same author also refers to the well-known copper-ores of Mansfeld, in Prussia, which occur in bituminous shales and bituminous limestone.[4]

A tree-trunk found embedded in the silver sandstones of Utah assayed at the rate of 5000 oz. of silver to the ton in the carbonised sapwood and bark. The hard silicified heartwood showed an assay value of only from 8 to 10 oz. of silver to the ton.[5] Tree-trunks in these sandstones are often covered and impregnated with horn silver.

Similar occurrences of copper-ores replacing the wood of trees and encrusting the leaves and stems of fossil plants have been discovered in the Triassic sandstones[6] of New Mexico, and in the Permian sandstones of Russia.[7]

The association of productive ores with carbon in one form or another, with carbonaceous and fetid limestones, and with base metallic sulphides, has been demonstrated in almost all parts of the globe.

Organic matter and sulphides, either singly or together, are powerful reducers of gold and base metals from their alkaline solutions.

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[1] R. L. Jack, *Annual Report of the Depart. of Mines*, Queensland, 1885, p. 58.

[2] J. Park, "The Geology and Veins of the Hauraki Goldfields," *Trans. New Zealand Inst. Min. Eng.*, vol. i., 1897, p. 52.

[3] Von Cotta, *Treatise on Ore Deposits*, p. 46.

[4] *Loc. cit.*, p. 164.

[5] W. P. Jenney, "The Chemistry of Ore Deposition," *Trans. Amer. Inst. Min. Eng.*, vol. xxxiii. p. 445, 1903; and C. M. Rolker, "The Silver Sandstone District of Utah," *Trans. Amer. Inst. M.E.*, vol. ix. p. 21.

[6] F. M. F. Cazin, "The Origin of Copper and Silver Ores in Triassic Sandrock," *Eng. and Min. Jour.*, vol. xxx. p. 381.

[7] Persifor Frazer, *Trans. Amer. Inst. Min. Eng.*, vol. ix. p. 33.

Paragenesis.

It has been shown by mining operations everywhere that certain minerals and ores are more frequently associated with each other than with other minerals. The genetic processes which caused the formation or deposition of a certain mineral often operated so as to cause the deposition of another mineral, or minerals, at the same time and in the same place.

This parallel, or synchronous, genesis of ores and minerals, which has brought about a common association in the matrix, is known as *paragenesis*, and is probably governed by the laws of chemical solution and precipitation. Substances soluble at the same temperature and pressure will pass out of solution together in the zone of decreased pressure or temperature. The causes which led to the constant association of certain minerals, such, for example, as gold and quartz, tin and wolfram, are still very obscure.

The following table, on the basis of that compiled by Von Cotta, affords a clear view of the ores and mineral commonly associated in metalliferous deposits :—

ASSOCIATED ORES AND MINERAL.

Two Members.	Three Members.	Four or More Members.
Galena, blende, .	Galena, blende, iron pyrites,	Galena, blende, iron pyrites, quartz.
Iron pyrites, chalcopyrite,	Iron pyrites, chalcopyrite, quartz,	Iron pyrites, chalcopyrite, galena, blende, quartz.
Gold, quartz, .	Gold, quartz, iron pyrites,	Gold, quartz, iron pyrites, blende, galena, arsenical pyrites.
Gold, tellurium, .	Gold, tellurium, quartz,	Gold, tellurium, iron pyrites, quartz.
Cobalt and nickel ores,	Cobalt and nickel ores, pyrrhotite,	Cobalt and nickel ores, pyrrhotite, quartz.
Tin-ore, wolfram, .	Tin-ore, wolfram, quartz,	Tin-ore, wolfram, quartz, tourmaline.
Cinnabar, iron pyrites,	Cinnabar, iron pyrites, quartz,	Cinnabar, iron pyrites, quartz, calcspar.
Magnetite, chlorite,	Magnetite, chlorite, garnet,	Magnetite, chlorite, garnet, pyroxene, pyrites.
Chromite, serpentine,	Chromite, serpentine, olivine,	Chromite, serpentine, olivine, pyroxene.

In a general way, experience has shown that tin, tungsten ores, and gold have a preference for siliceous rocks ; and iron, chromium, platinum, nickel, and copper for basic rocks.

Rock Temperatures in Deep Mining.—Until recent years it was believed by physicists that the increase of temperature, namely, 1° Fahr. for every 60 feet, observed in the driving of the Saint Gothard tunnel, was the normal rate in all parts of the crust of the earth. This belief is now known to be erroneous. Observations taken in deep mines and bore-holes in different parts of Europe, America, and Australia, during the past decade, have proved that:—

(*a*) The temperature of the crust increases with the distance from the surface.

(*b*) That the ratio of increase of temperature to depth, *i.e.*, the temperature-gradient, is not the same in all places.

(*c*) That the temperature-gradient is not uniform for all depths even in the same place; that is, isogeotherms are not parallel in the upper part of the crust.[1]

(*d*) That the temperature-gradient increases with the depth.

In the Comstock lode, which is enclosed in andesites of middle Tertiary date, the temperature was found to rise 1° Fahr. for every 30 feet in depth.[2] This increase is exceptional and apparently caused by a strong upward flow of heated waters in the vein-fissures. The geologic conditions suggest the waning phases of solfataric action as the source of the heated waters.

At the Ohaeawai quicksilver mines in New Zealand, the rock-temperature increased so rapidly that boiling water was met with at a depth of 200 feet from the surface. Here again we are manifestly dealing with expiring volcanic heat. The basalt cap of quite late Tertiary date, the hot springs, and sinters, sulphur, and cinnabar deposits leave little room for doubt in this instance.

Volcanoes, whether recent or Tertiary, are situated in abnormally hot parts of the crust. Some parts, however, are abnormally cool. For instance, Professor Agassiz found in the Calumet and Hecla mine at Lake Superior, a rise of only 1° Fahr. for every 223 feet in depth.[3]

In four gold-mining centres in Victoria,[4] the increase of temperate was found to be as follows:—

South Maldon Mine, Maldon—
1° Fahr. for every 81 feet in depth down to 1700 feet.

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[1] Professor Redmayne, "Underground Temperatures," *South Staffordshire and East Worcestershire Inst. Min. Eng.*, 1904.

[2] G. F. Becker, "The Geology of the Comstock Lode," *Monograph III.*, p. 263, 1882, *U.S. Geol. Survey*, Washington.

[3] Professor Agassiz, *American Journal of Science*," vol. i., 1895, p. 503.

[4] H. C. Jenkins, "Rock Temperatures in Victoria," *Proc. Aust. Assoc. Adv. Sc.*, vol. ix. p. 309, 1902.

South Garden Gully, Bendigo—
1° Fahr. for every 77 feet in depth down to 3000 feet.
Band and Albion Mine, Ballarat—
1° Fahr. for every 80 feet in depth down to 2080 feet.
New Chum Railway, Bendigo—
1° Fahr. for every 77·5 feet in depth down to 3645 feet.

The country-rock in each case is Silurian slate and sandstone.

The following tables of rock-temperatures prepared by Professor Everett,[1] are of much interest in connection with this question.

TABLE I.—OBSERVATIONS OF TEMPERATURE AT MINES AND VERTICAL BORINGS.

	Temperature (Degrees Fahr.).	Depth (feet).	Feet per Degree of Increase.
Paruschowitz (Silesia),	157	6445	60
Schladebach (near Leipsic),	134	5630	67
Sperenberg (near Berlin),	116	3492	51½
Wheeling (West Virginia),	110	4462	74
Pendleton (near Manchester),	100·6	3480	66
Port Jackson (N.S.W.)	97	2733	80
Rosebridge (near Wigan),	94	2445	54
Dukinfield (Manchester),	86½	2700	72
Ashton Moss (near Manchester)	84	2880	82
Tamarack (Lake Superior),	84	4450	100
Scarle (Lincolnshire),	79	2000	69
Kingswood (near Bristol),	75	1769	68

TABLE II.—DEPTHS AT WHICH 100° FAHR. WAS FOUND.

	Feet.
Sperenberg,	2400
Paruschowitz,	3200
Schladebach,	3400
Pendleton,	3480
Wheeling,	3875

TABLE III.—CALCULATED DEPTHS AT WHICH 100° FAHR. WOULD BE FOUND.

	Feet.
Rosebridge,	2769
Scarle,	3449
Kingswood,	3469
Dukinfield,	3672
Wheeling,	3722
Ashton Moss,	4192

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[1] Professor J. D. Everett, *Evidence before the Royal Commission on Coal Supplies*, London, 1904.

From these figures it will be seen that the calculation of average temperature-gradients has no meaning except for comparative purposes among mines in the same place and in the same class of country-rock.

In the Wheeling oil-well, both when dry and full of water, the increase of temperature was 1° Fahr. for every 80 to 90 feet in the upper portion, and 1° for every 60 feet in the lower part.

The greatest depth reached by man is only equal to one-tenth of the vertical height of the irregularities of the surface. Hence it is almost certain that in such shallow depths the rise of temperature will be influenced by the thermal conductivity of the rocks to a greater degree than at depths of several miles, where the temperatures due to pressure or gravitational stress will be more uniform.

The thermal conductivity of rocks is subject to great variation, but, generally speaking, that of basic rocks is higher than that of acid rocks, and of dense rocks than of porous rocks, but to what extent these conditions tend to modify rock-temperatures has not yet been ascertained. Concerning the thermal conductivity of rocks under pressure practically nothing is known.

The rise of temperature due to gravitational stress is an important factor, and in seeking for the source of the earth's internal heat it must not be overlooked. At present some physicists incline to the belief that the internal heat is due to the presence of radio-active minerals.

Assuming the average density of the crust to be 3, the pressure at a depth of 10 miles would amount to 30·6 tons per square inch. At a depth of 100 miles, it would be 306 tons per square inch, a pressure which brings us almost to the point of viscosity of the hardest steel. The heat equivalent to this pressure, even at this comparatively shallow depth—one-fortieth of the semi-diameter of the earth—would be sufficient to liquefy all known rocks. But the pressure will prevent liquefaction, with the result that the rock-material must exist in a condition of great tension, far above the point of viscosity, ever ready to penetrate and ramify every crack and plane of weakness presented to it.

The pressure-heat will radiate upwards, warming the higher portion of the crust, imparting to it a temperature above that normal to the pressure at any given depth. The internal heat of the earth must be largely due to the gravitational stress of its own mass; and volcanic eruptions may be merely the local effusions of rock-material that has been suddenly relieved from a pressure above its point of viscosity.

Recording Rock Temperatures.—When we remember how dependent the problem of deep-mining is upon rock-temperature, it is remarkable how little trustworthy information has been recorded in regard to progressive underground temperatures, even in places where mining has been carried on for generations. The time is approaching when the recording of rock-temperatures must be systematically undertaken in all deep mines.

Temperatures should be noted with reasonable skill and precision at regular intervals both when sinking and driving in new ground; and at all places where there is a change of rock. Observations taken in a careless or haphazard manner are of no value, and in some cases may even be worse than useless, as they may lead to the formation of erroneous conclusions.

The precautions to be observed in taking underground temperatures have been succinctly summarised by H. C. Jenkins[1] as follows:—

(1) Temperatures should be taken in *new ground*, that is, in the face or heading freshly broken, where the work is being rapidly pushed ahead. The rock-walls soon become cooled by ventilating currents.
(2) Where possible the rock should be free from sulphides easily oxidised, since chemical reactions attending oxidation are exothermic. When sulphides are present the temperature should be taken at once.
(3) Very wet ground must be avoided, as it will generally give a lower reading than the true one, since the water will in most cases be descending surface-water. On the other hand, ascending deep-seated water will tend to exaggerate the temperature.
(4) After drilling, sufficient time must be given to permit the abnormal heat of drilling to dissipate itself before taking a rock-temperature. A few minutes will generally suffice for this.
(5) The drill-hole must be deep enough to avoid the temperature of the face of rock. Agassiz used holes 10 feet deep. In the majority of cases 6 feet holes are sufficient.
(6) The bore-holes should be horizontal by preference.
(7) The temperatures should be taken with a high-class clinical thermometer, graduated from, say, 80° to 115° Fahr. and reading to 0·05° Fahr., and corrected against a standard thermometer. When inserted in the hole, the thermometer should be wrapped round with three layers of flannel.

Limits of Deep Mining.—Mining at great depths will be limited by the underground temperature and economic considera-

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[1] H. C. Jenkins, "Rock Temperatures in Victoria," *Proc. Aust. Assoc. Adv. Sc.*, vol. ix. p. 309, 1902.

tions. By the adoption of secondary ventilation and methods of refrigeration mining could doubtless be carried on at depths ranging up to 6500 feet according to the local increment of temperature.

Metasomatic Replacement.—Until lately it was commonly believed that ore-deposits merely filled pre-existing fissures and cavities in country-rock. In recent years writers on ore-formation have been inclined to place more or less stress on what has been termed *metasomatic replacement.*

According to this, it is surmised that, in many cases at least, no previous cavities existed, but that the waters percolating through the rocks dissolved certain tracks or zones which they replaced with ore-matter and gangue.

This process of replacement is well known to petrologists to have taken place among the constituents of many rock-masses, no matter how dense, including all metamorphic rocks, and all older igneous and eruptive masses.

It is known as metasomatism (meaning change of body), and is due to internal chemical reactions, which seem to take place as readily in rocks as do the metabolic changes in living organisms.

In many cases minerals are replaced molecule by molecule, giving rise to what is termed mineral pseudomorphism. But in the processes which affect changes in rock-masses, reactions are set up between the different constituent minerals, thereby forming new minerals capable of segregating themselves into masses of all sizes.

Gneiss and mica-schist are familiar examples of the work of segregation and molecular rearrangement of the dominant constituents of altered sedimentary rocks. Such alteration is termed anamorphism and always takes place in the anamorphic zone.

The internal changes that affect eruptives are known to every petrologist. Besides these changes, which are chiefly molecular, rock-masses, and especially eruptive rocks, may be so altered by the action of circulating waters as to bear no resemblance to the original rock.

Thus in many cases andesites have been changed to propylite by the removal of certain essential constituents and the substitution of others. Rock replacement is doubtless preceded by alteration.

Metasomatic replacement, as defined by Van Hise[1] and Emmons,[2] does not necessarily imply a mere substitution of matter, molecule for molecule, as happens in the process of pseudomorphism, which involves the preservation of the original form of the sub-

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[1] Van Hise, 16*th Annual Report U.S. Geol. Survey*, Part I., p. 689.

[2] S. F. Emmons, *U.S. Geol. Survey, Monograph XII.*, p. 565.

stance replaced, but an interchange of substance, the dissolved rock being replaced by grains or crystalline aggregates of one or more minerals.

That substitution did, however, take place in some kinds of deposits is well known. In the tin-impregnations in granite, in New South Wales, pseudomorphs of tin-oxide, in the form of orthoclase, are not uncommon ; and many other examples could be quoted, having reference principally to the replacement of isolated crystals, in crystalline and eruptive rocks.

Slow replacement of substance by a progressive movement of the solutions in a definite direction must be assumed to have taken place in the formation of ore-deposits composed of massive aggregates. In most cases the direction of movement would be determined by a rock fracture or line of fault.

In the case of deposits formed by deep-circulating solutions, it is manifest that circulation could not be rapid, as the face or breast where metasomatic processes were active would form a blind end or *cul-de-sac.* Whatever circulation existed would be due to convection currents, which in deep-seated cavities could only be feeble.

This now raises the question as to the transference and supply of dissolved matter to the continually advancing faces of metasomatic action.

The energy which caused, or at any rate accelerated this transference, was probably osmotic pressure, which has been shown by van 't Hoff to be a force of great intensity.

It has been proved that when a portion of dissolved substance is deposited from a solution at any point, the osmotic balance is disturbed ; and immediately more dissolved matter travels to that point in accordance with the well-established laws of osmotic diffusion, thereby providing new matter to augment the growing mass of ore.

Arrhenius and Gillette have urged the claims of osmotic pressure to be considered a factor in ore-formation.[1]

Osmotic pressure is the chemical principle which compels solutions to maintain an equal state of concentration throughout their whole mass, and since it is always called into being when deposition commences, its operation as an agency in vein-filling must have been assumed by writers on this subject, although seldom specifically mentioned.

Metasomatism is a process of lode-formation by replacement, and does not concern itself with the source or origin of the dissolved matter contained in the solutions.

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[1] Gillette, "Osmosis as a Factor in Ore Formation," *Trans. Am. Inst. M.E.*, 1903.

It is almost certain that metasomatic processes, to a greater or less degree, were active agencies in the formation of many underground ore-deposits and rock masses. For this reason the phrase *Replacement lode*, so often applied to large pyritic ore-bodies and to mineralised zones of country, is somewhat ambiguous, and possesses no definite genetic significance.

Veins in which the mineral contents are arranged in symmetrical bands or layers can only be satisfactorily explained by supposing that the vein-matter was deposited in open channels, beginning with a layer on each wall, followed by subsequent layers until the channel became closed or the solutions exhausted.

It is not assumed that the vein-fissure remained open its full width during the whole period of deposition of the vein-matter. It is more reasonable to suppose that the fissure gradually opened as the process of deposition proceeded, the newly formed matter affording the necessary support to the walls. The forces which initiated the fracture, if still in existence, would doubtless tend to reopen and widen the fissure from time to time.

Waldemar Lindgren's classic paper on "Metasomatic Processes in Fissure Veins"[1] represents a great advance in the scientific investigation of vein-formation. The author has followed Stelzner's methods of microscopic chemical research with conspicuous success, in a field hitherto much neglected.

His work further shows that a clear understanding of the genesis of a vein can only be obtained by a minute study of the rocks contiguous to the ore-body.

The metasomatism he describes is clearly not correlative with the metasomatic replacement defined by Emmons, but merely mineral pseudomorphism on a large scale. He defines his standpoint by repeating and adopting Becker's statement[2] that "the theory of the substitution of ore for rock is to be accepted only when there is definite evidence of pseudomorphic molecular replacement."

He mentions that quartz is found replacing calcite, or even orthoclase, and that rutile and anatase are common as secondary products after ilmenite, biotite, etc.

Upon these and other mineralogical replacements, which he enumerates, he apparently assumes that vein-filling was the result of replacement molecule by molecule.

This somewhat narrow view of metasomatic replacement is manifestly insufficient to explain the genesis of the banded chalcedonic veins of the Hauraki region of New Zealand.

Lindgren thinks this genetic theory may be fully sufficient

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[1] Lindgren, *Trans. Am. Inst. M.E.*, vol. xxx. p. 578, 1900.

[2] Becker, Discussion, *Genesis of Ore Deposits*, 1901, p. 204.

for many veins, but admits that for many others—perhaps the majority of fissure-veins—there seems to be something lacking in this explanation.

Vogt classifies the metasomatic processes caused by the circulation of ore-solutions[1] as follows :—

(*a*) Alteration forming greisen, cassiterite rock, etc.
(*b*) Scapolitisation.
(*c*) Propylitisation.
(*d*) Kaolinisation.
(*e*) Sericitisation.
(*f*) Carbonatisation (with dolomitisation).
(*g*) Silicification.
(*h*) Zeolitisation.
(*i*) Intense contact metamorphism.

He agrees with Emmons, Becker, Lindgren and others that metasomatic replacement plays an important part in the formation of mineral-veins and ore-bodies.

Information with regard to vein-structure, character, and influence of wall-rock should be placed on record on all possible occasions. A petrographical examination of the vein-matter and wall-rock for some distance on each side of the ore-body will often throw much light on the genesis of the ore; but care must be taken in forming generalisations on microscopic evidence alone.

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[1] Professor Vogt, "Problems in the Geology of Ore Deposits," *loc. cit.*, p. 660.

CHAPTER IV.

THE DYNAMICS OF LODES AND BEDS.

CONTENTS:—Definition of Faults—Faults parallel with Bed—Dip Faults—Step Faults—Trough Faults—Rules for Inclined Lodes—Zimmermann's Graphic Method.

Definition of Faults.—Mineral beds and veins may be bent or fractured, elevated or depressed, by the slow secular movements which build up continental areas; or tilted and dislocated by the sharper movements propagated by the intrusion of an igneous magma; that is, the disturbing agents may be orogenic or hypogenic.

Dislocations without movement of the rock on either wall are simple fractures; but in the majority of cases there has not only been fracture but also displacement. In other words, the rents have become faults.

A fault may be defined as a fracture on one side of which movement has taken place whereby the rocks on one side have been displaced relatively to those on the other side.

Faults are caused by crust stresses. They run in all directions, but the major faults of a region often run in the same general direction.

A fault may run parallel with the course, or strike, of a bed or vein; or cross the course at right angles, or at any other angle.

Faults are not often vertical, but incline to one side or the other. A fault is said to hade when it inclines from the vertical plane. The hade of a fault is, therefore, the angle which the fault makes with the vertical plane.

The hade-line of a fault is the oblique resultant of two principal component forces, namely gravitational stress acting vertically or radially towards the centre of the earth, and lateral thrust mainly due to subsidence.

Faults are of two kinds, namely:—

(*a*) *Normal faults.*
(*b*) *Reversed or overlap faults.*

In normal faults the downthrow is towards the side to which the fault hades.

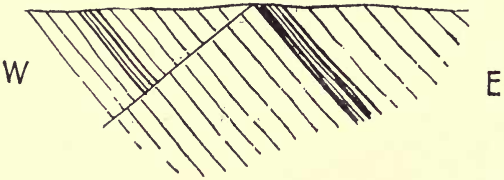

Fig. 45.—Normal Fault.

In Fig. 45 the hade of the fault and downthrow of the beds are towards the west.

In reversed or overlap faults the downthrow is on the foot-wall side of the fracture.

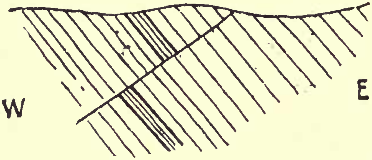

Fig. 46.—Reversed or Overlap Fault.

In the above figure, the hade is to the west, and the downthrow on the foot-wall side.

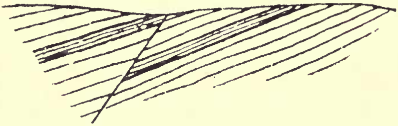

Fig. 47.—Reversed or Overlap Fault.

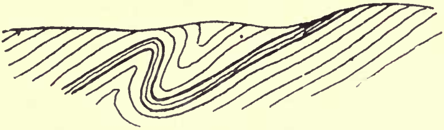

Fig. 48.—Sharp Folding without Fracture.

Reversed faults are intimately connected with sharp anticlinal and synclinal folding. The stresses introduced by the bending of beds are often relieved by faulting and shearing.

Faults parallel with Bed or Vein.—Faults produce different effects according to the direction of their strike and dip, relatively to the strike and dip of the veins or beds which they intersect.

A fault which runs parallel with the strike of a bed is termed a *strike-fault.* It may dip with the bed or against it. In figs. 50 and 51, the faults dip in the same direction as the beds. In figs. 49 and 52, the beds and faults dip in opposite directions.

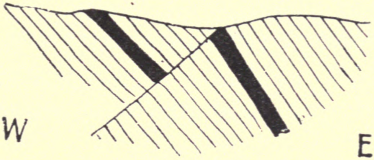

FIG. 49.—Strike Fault dipping West and Seam dipping East.

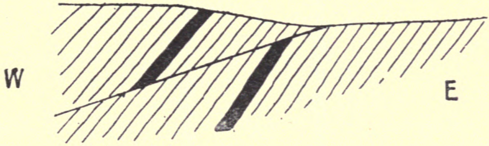

FIG. 50.—Strike Fault dipping in the same Direction as the Seam, at a Flatter Angle.

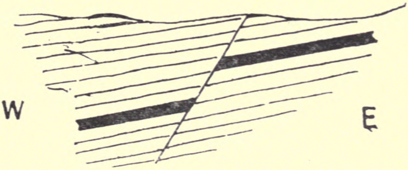

FIG. 51.—Strike Fault dipping in the same Direction as the Seam, at a Steeper Angle.

It should be noted that the faults shown in the last three figures are normal faults.

A strike-fault causes vertical and horizontal displacements of the seam or vein intersected.

The vertical line *ab* shows the vertical displacement called by miners *downthrow* or *upthrow*, according as the fault is approached from the east or west.

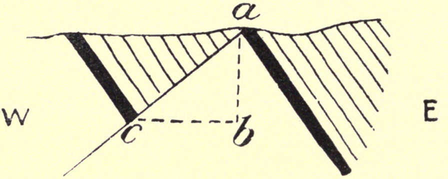

FIG. 52.—Showing Displacements by Strike Fault.

The line *cb* shows the amount of horizontal displacement or disseverment which is sometimes erroneously termed *heave.*

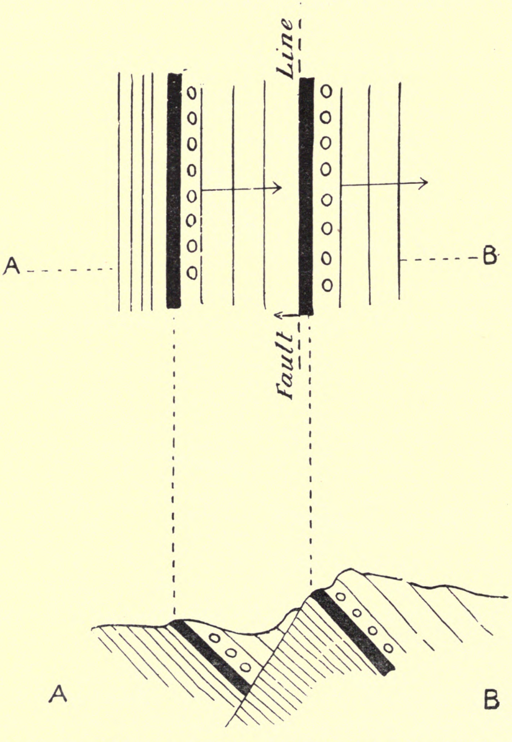

FIG. 53.—Upper part, Plan of Beds traversed by Strike Fault. Lower part, Cross-section of Beds along line AB, showing repetition of dislocated beds.

When a fault displaces stratified rocks, the lines of bedding afford a measure of the vertical displacement; but in the absence of bedding-planes or some rock marked by a distinctive peculiarity of colour or composition, there is no certain means of measurement.

A strike-fault causes no lateral displacement of the beds, which it intersects; but when the beds are inclined, it may produce a repetition of the dislocated beds, as shown in fig. 53.

In regions which have been subject to long-continued denudation, one side of a faulted seam may be entirely removed, as shown in fig. 54. This is not uncommon in the case of young Secondary and Tertiary coal-measures hanging on the flanks of mountain chains.

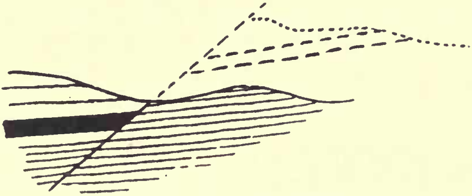

FIG. 54.—Section of Normal Fault, showing one side of seam removed by denudation.

The seam may be partly removed by denudation on one or both sides of the fault, as indicated in figs. 55 and 56.

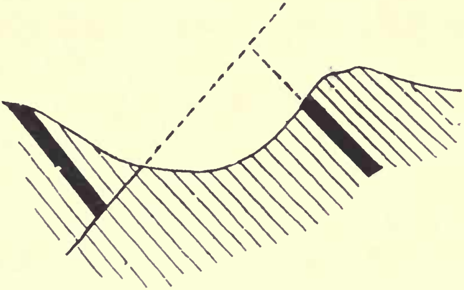

FIG. 55. —Section showing Seam partly removed on One Side along line of Fault.

When a fault possesses the same dip and strike as a seam or mineral-vein, that is, when it conforms to the bedding-planes, it causes no apparent disturbance in the relation of the rocks on each side.

The only evidence of the existence of such a fault is the smooth, polished, and slicken-sided surfaces on the line of movement. In the case of a mineral vein, the faulting may result in the production of a layer of friction breccia on the side on which the movement took place.

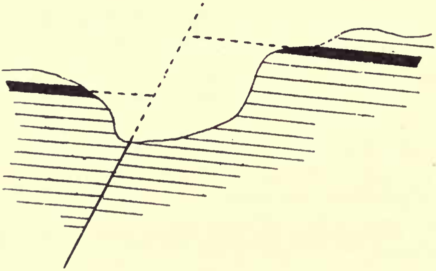

FIG. 56.—Section showing Seam partly removed on Both Sides along line of Fault.

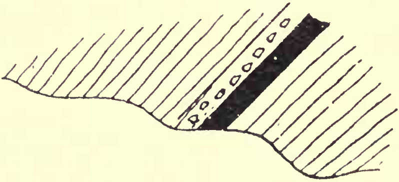

FIG. 57.—Section of Parallel Thrust Plane.

Such a fault is merely a thrust-plane, more often the result of shearing thrust than vertical or tangential stress.

Dip Faults.—A fault which runs in the same general direction as the dip of a bed or vein, is termed a *dip-fault.*

The distinction beween strike-faults and dip-faults is not always well marked. A fault may pursue any course between the strike and dip of a bed. When its course is midway between the dip and strike of the bed, the fault may be termed either a dip-fault or a strike-fault.

Dip-faults produce an *apparent* lateral displacement of the bed or vein, which they cross.

When faulting takes place, the principal movement is a vertical one. Consequently, when the faulted vein is vertical there is no lateral displacement or heave, as the dissevered ends merely slide upon each other.

Evidences of lateral thrust and shearing are often observed among Palæozoic schists and gneiss, but are sometimes seen in fault-planes. Thus in some cases the dissevered ends of a vein are sharply bent towards each other, where they abut against the fault.

On the slicken-sided faces of great faults, the striæ caused by the rubbing of one rock-surface upon the other generally follow a vertical plane.

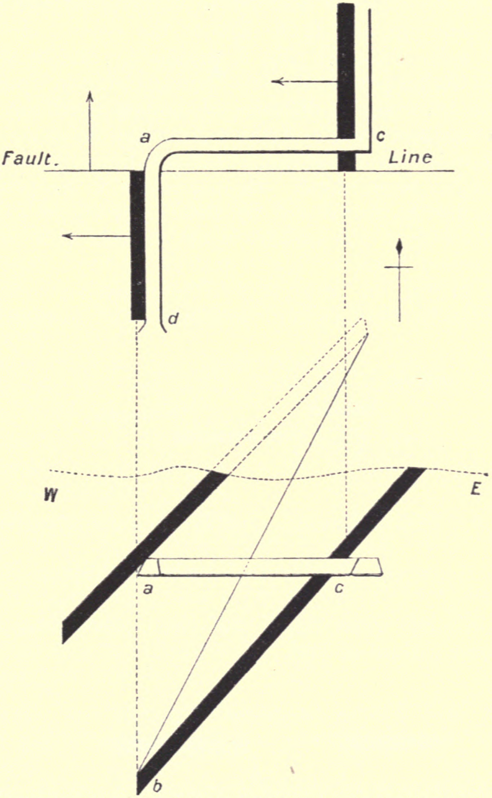

FIG. 58.—Upper part, Plan of Faulted Vein at, say, 100 feet level. Lower part, Cross-section along *ac*, showing heave and vertical displacement.

The apparent heave or lateral displacement is produced by the dip of the vein carrying the vein to the right or left; and manifestly the flatter the dip, the greater will be the apparent displacement. When the vein is vertical, there can be no heave at all.

In fig. 58 the distance *ab* represents the amount of vertical displacement or downthrow; and the cross-cut *ac* the amount of lateral displacement or heave.

When the drive *da* in fig. 58, reached the fault, the vein was lost. The lost vein was found at point *c* by cross-cutting towards the east; but obviously the part of the vein struck at *c* was not the part corresponding to that driven on along *da* (fig. 58).

In this example, the fault dips to the north; therefore, the downthrow is on the north side of the fault. Hence, the crosscut will strike a higher part of the vein than that driven upon along *da*.

The downthrow is the distance *ab*, and at *b* will be found the continuation of the portion of the vein driven on at *a*.

Sometimes two or more faults run parallel with each other, or cross each other at an angle. In other cases, it happens that one group of faults is intersected by another group of a later date. When faulted veins or seams are again faulted, many complicated problems become involved in the recovery of the lost portions.

Step Faults.—A seam or bed is sometimes crossed by a number of faults, running more or less parallel to each other, and dipping in the same direction; or by some dipping one way and some another.

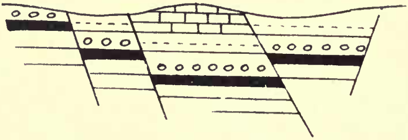

Fig. 59.—Cross-section showing Group of Step Faults.

Such faults are often small, and their effects best seen when they dislocate a seam of coal.

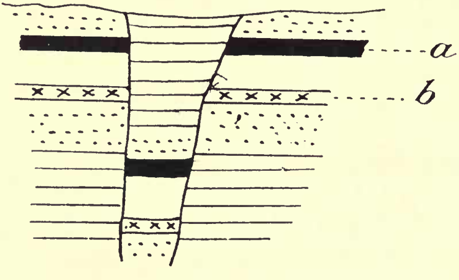

Fig. 60.—Cross-section of Trough Fault in Dudley Port Mine, Staffordshire. (*a*) Seam of coal. (*b*) Basalt.

Trough Faults.—When two parallel faults dip towards each other, permitting a portion of strata to be thrown down between them, they form what is spoken of as a *trough-fault.* A well-known example is the trough-fault of Dudley Port Mine, in Staffordshire, which has thrown down the great 10-yard seam a distance of 450 feet, as shown below.

RECOVERY OF LOST LODES.

Rules for Inclined Lodes.—Four cases may occur when driving on a vein dislocated by a fault. The vein may dip to the right or left hand, and the fault towards you or away from you.

I. When the vein dips to the left, and is cut off by a fault dipping towards you, the lost vein will be found by driving to the left.

II. When the vein dips to the left, and is cut off by a fault dipping away from you, the lost vein will be found by driving to the right.

III. When the vein dips to the right and is cut off by a fault dipping towards you, the lost vein will be found by driving to the right.

IV. When the vein dips to the right, and is cut off by a fault dipping away from you, the lost vein will be found by driving to the left.

The fault may cross the face of the drive squarely, or it may cross obliquely. The angle at which the fault intersects the vein does not affect the application of the rules.

V. When a horizontal seam is cut off by a fault dipping towards you, its continuation will be found at a higher level; but when the fault dips away from you, the lost seam will be found underfoot.

These rules are always true, except in the case of reversed faults and strike-faults which run parallel with the strike of the vein or seam.

Zimmerman's Graphic Method.—Zimmerman's graphic method for finding the lost or faulted portion of a lode is as follows:—

1. Lay down upon paper the line of strike of the lode and fault, producing the lines till they intersect.
2. Determine by construction the point of intersection at any imaginary lower level.
3. Draw a line joining the points of intersection of the lode and fault at the two levels.

4. Produce the line of intersection through the fault at upper level.
5. Draw a line perpendicular to the fault at the point where the line of intersection emerges from the fault.

Rule.—On whatever side of the line of intersection produced the perpendicular falls, on that side will the lost lode be found.

Zimmerman's law is always true, except in the case of reversed faults and strike-faults.

Unless beds can be recognised on each side of the fault, the extent of the throw cannot be determined.

Application of Rule. Example 1.—Suppose that in driving north on a lode a fault is met with which displaces the lode. The fault dips south at an angle of 45°, and the lode dips west at an angle of 60°. In which direction should the lost portions of the lode be found?

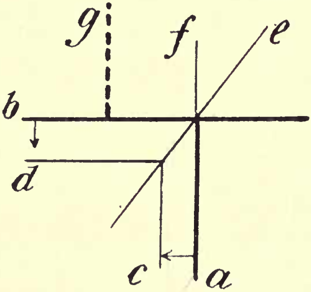

FIG. 61.—Sketch Plan to illustrate Example 1.

Procure a sheet of paper and plot the approximate position of the lode and fault, showing the direction of dip of each with an arrow. Let the lode and fault be shown by a firm, black line, as shown in fig. 61.

Plot the position the lode and fault would occupy at a lower depth, say, at 100 feet, representing them by a thin line. Produce the lines till they meet. The approximate positions at a lower level can be plotted by inspection, for it is evident that if the lode dipping at 60 deg. travels out, say $\frac{1}{4}$ inch in 100 feet, the lode dipping at the flatter angle of 45 deg. will dip much faster, and hence travel relatively further out.

The exact departure or distance the lode and fault will travel out in 100 feet can be found by multiplying the cotangent of the angle of dip by 100.

Draw a line through the points of intersection, and erect a perpendicular to the fault. It will be seen that the perpendicular falls on the left side of the intersector; hence the lode will be found by driving to the left.

It will be seen that the line of intersection, before the perpendicular is erected, crosses the fault so as to make an acute and an obtuse angle. In all cases, the heaved portion of vein will be found on the side of the greater angle. Hence the drawing of the perpendicular is unnecessary to the solution of the problem.

Example 2.—Suppose the fault in the last example dipped to the north instead of south at the same angle, the lode would be thrown to the right, as shown by fig. 62.

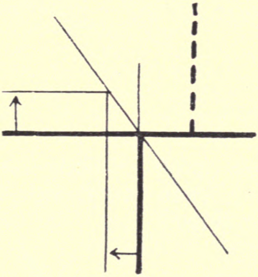

FIG. 62.—To illustrate Example 2.

Example 3.—Suppose a lode were running N.-S., and dipping east at an angle of 55°, and were intersected by an E.-W. fault dipping south at an angle of 60°, where would the lost lode be found?

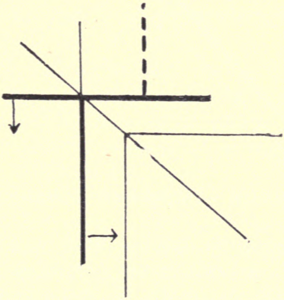

FIG. 63.—To illustrate Example 3.

Example 4.—Suppose, in Example 3, the faults were dipping north instead of south, at the same angle, the diagram would be as shown below.

Example 5.—Suppose in driving north-west on a lode dipping south-west at an angle of 60°, a fault were met with running E. and W., and dipping north at an angle of 75°, on which side would the lost lode be found?

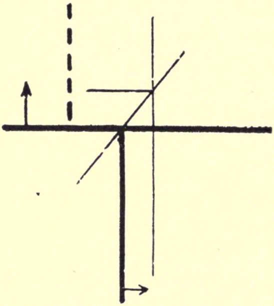

FIG. 64.—To illustrate Example 4.

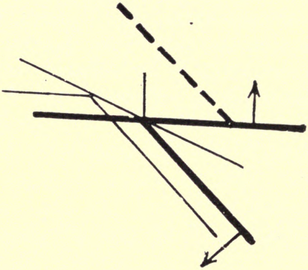

FIG. 65.—To illustrate Example 5.

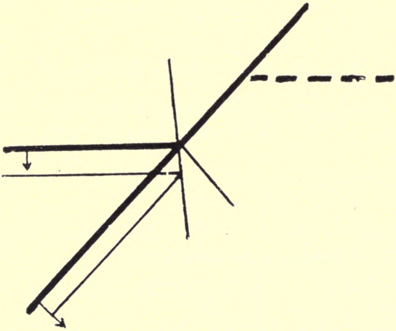

FIG. 66.—To illustrate Example 6.

Example 6.—Suppose in driving east on a lode dipping south at an angle of 35°, a fault were met with running N.E.-S.W., and dipping S.E. at an angle of 60°, where should the lost portion of the lode be found?

CHAPTER V.

ORE DEPOSITS GENETICALLY CONSIDERED.

CONTENTS :—Genetic Classification — Magmatic Segregation — Chromite in Peridotite — Nickel Iron—Native Copper — Platinum Metals — Ores formed by Eruptive After-actions — Solfataric — Action of Ascending Alkaline Waters—Fumarolic—Contact Metamorphic Deposits—Regional Metamorphic Deposits—Meteoric Waters—Organic.

ORE-DEPOSITS are of diverse form and composition. They are found as true veins, as detached masses, and as members of a sedimentary formation. It is now known that their mode of occurrence, and, to some extent, their composition and form, were determined by the geological conditions prevailing at the time of their formation.

In the past decade, a vast mass of facts has been added to the literature of the subject, particularly in America, where the magnitude of the operations connected with mining has afforded great facilities for observation and research.

The genesis of ore-deposits presents many difficult problems, and naturally the literature of the subject is rich in theoretical deductions.

The introduction of petrographical methods of investigation, and the demonstration of the principles of metasomatic replacement and secondary enrichment, have marked a new point of departure, and led to a truer conception of the formation of ore-deposits than formerly existed.

In this investigation we must remember that existing conditions are but a reflection of the past. The agencies that built up the crust of the earth in its present form are still in operation, and still governed by the same natural laws.

We are living on the edge of a geologic epoch, and if we would rightly understand the past, we must study the present. The occurrence of ore-deposits is merely a geologic happening—an incident in the tectonic arrangement of the materials forming the outer shell of the globe.

Recent petrographical investigation has shown that ore-deposits are always more or less intimately connected with igneous rocks. This constant association naturally leads to the broad generalisation—*That ore-deposits are genetically connected with the eruption of igneous magmas.*

Genetic Classification.

The genetic classification which seems to most nearly satisfy our present knowledge relating to mineral deposits is as follows:—

I. Magmatic segregation.
II. Eruptive after-actions—
    (*a*) *Solfataric.*
    (*b*) *Fumarolic.*
    (*c*) *Contact metamorphic.*
    (*d*) *Regional metamorphic.*
III. Meteoric waters—
    (*a*) *Chemical.*
    (*b*) *Mechanical.*
IV. Organic.

I.—MAGMATIC SEGREGATION.

It has been shown by Professor Sandberger and others, that igneous rocks contain all the constituents of mineral veins.

Professor Vogt, of Christiania, maintains that a deep-seated inaccessible repository of the heavy metals can no longer be sustained.[1] Modern geologists, he points out, have abandoned the old conception of the earth's interior condition, which supposed that the interior was an enormously compressed liquid molten mass of high specific gravity charged with heavy metals.

The composition of the molten magmas that have issued at the surface in successive geological ages, does not favour any hypothesis which assumes the existence of a greater proportion of the heavy metals in the barysphere than in the upper crust or lithosphere.

Referring to the distribution of the elements in the earth's crust, Vogt states that of the entire crust, including the rocks, sea and atmosphere, oxygen constitutes by weight about one-half, and silicon above one-quarter.[2]

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[1] Professor J. H. L. Vogt, "Problems in the Origin of Ore Deposits," *Genesis of Ore Deposits*, 1901, p. 637.

[2] *Loc. cit.*, p. 639.

The proportions of the other elements are, he says, as follows :—

	Per cent.
Aluminium, iron, calcium, magnesium, sodium, and potassium, . .	10 to 1
Hydrogen, titanium, carbon, and chlorine,	1 to 0·1
Phosphorus, manganese, sulphur, barium, fluorine, nitrogen, zirconium, and strontium, ...	0·1 to 0·01
Nickel, lithium, vanadium, bromine, and perhaps beryllium and boron, .	0·01 to 0·001
Cobalt, argon, iodine, rubidium, tin, cerium, yttrium, possibly arsenic and others, ...	0·001 to 0·0001

In igneous magmas deficient in acid-forming constituents, the heavy metals will segregate as oxides during the process of cooling, assuming the form of individual crystals, grains, or irregular aggregates in small and great masses.

The petrographical researches of Vogt and Brögger disclosed in basic dykes a tendency of the heavy minerals to segregate near the borders. The occurrence of massive mineral-aggregates near their borders is a marked characteristic of peridotites and serpentines in all parts of the globe.

For physico-chemical reasons, mineral segregations are more common in basic and ultra-basic rocks than in acid rocks.

The most typical examples of magmatic border-segregation are found in peridotite and its serpentinised forms. At present the laws governing magmatic differentiation are but imperfectly understood. By some, segregation is ascribed to molecular flow due to differences of temperature in the magma ; by Becker and Spurr to convection currents which they believe would tend to carry the first crop of minerals, such as magnetite, olivine, etc., to the borders of the igneous magmas.

The writer[1] believes that border segregation may be accelerated due to unequal osmotic pressure in the cooling magma. The temperature at the borders of the igneous mass would be less than in the central portion, thereby causing a corresponding difference of osmotic pressure. And since osmotic pressure holds good for the laws of thermodynamics, there would be a transference of osmotic stress from the central portion to the borders.

The ores that occur as primary constituents of intrusive rocks,

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[1] J. Park, "The Cause of Border Segregation in Some Igneous Magmas," *Trans. N.Z. Inst.*, vol. xxxviii., 1905.

resulting from direct differentiation in the cooling magma, are as follows :—

(*a*) Chromite in peridotite and serpentine.
(*b*) Copper and nickel-iron in serpentine.
(*c*) Platinum metals in highly basic eruptives.
(*d*) Magnetite and titanite in basic and semi-basic eruptives.

Chromite in Peridotite.—In the South Island of New Zealand, there are two mountain masses of peridotite, in which the magmatic segregation of chromite is exhibited on a large scale.

A few miles from the city of Nelson, Dun Mountain rises to a height of over 4000 feet above sea-level. It covers an area of about 4 square miles, and is composed of massive olivine, in which chromite of iron is uniformly disseminated in the form of fine grains, but occasionally occurs in large masses.[1]

The adjacent rocks are slaty shales and limestones of probably Jurassic age, the limestone occurring at the base of sedimentary formation. Between the limestone and the olivine, to which Hochstetter[2] gave the distinctive name dunite, there is a belt of serpentine half a mile wide.

The serpentine contains lenticular-shaped masses of chromite, native copper, and copper ores, principally chalcopyrite, with the usual products of oxidation. It also contains thin irregular veins of diallage, bronzite, enstatite, scapolite, wollastonite, and chrysotile.

The larger masses of chromite in the olivine and serpentine occur along the margin or boundary of these rocks.

The second great mass of peridotite forms Red Mountain, situated 20 miles north of Milford Sound, in Otago.[3] It is over 6000 feet high, and covers an area of about 10 square miles.

The mountain is composed of olivine and chromite. The latter occurs in much greater proportion than at Dun Mountain.

The peridotite is flanked on two sides by belts of serpentine, which separate it from the adjacent slates and sandstones of supposed Palæozoic age.

The olivine, near the contact with the sedimentary rocks, is often so highly charged with chromite as to form massive bodies of ore. No deposits of chromite are known in the serpentine, but

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[1] S. H. Cox, "Chrome Deposits of Nelson," *New Zealand Geol. Reports and Explorations*, 1881, p. 8.

[2] Dr F. Von Hochstetter, *Zeitschrift der deutschen geol. Gesells.*, xvi. p. 341, 1864.

[3] J. Park, *New Zealand Geological Reports and Explorations*, 1886-87, p. 121.

they may possibly exist, as the country is still practically unexplored.

Nickel Iron.—The sands in the streams which drain the Red Mountain serpentine area yield small quantities of the rare nickel-iron alloy, Awaruite, discovered by W. Skey in 1885.[1] It has been found, *in situ*, in the serpentine.[2]

A nickel-iron alloy, the same as or related to Awaruite, has been found in gold-bearing sands at the River Biella, Piedmont, associated with chromite separated from peridotite;[3] in serpentine in Josephine County, Oregon;[4] in sandstone, associated with chromite, in Fraser River, British Columbia;[5] and in Smith River, Del Norte County, California.

Native Copper.—The association of copper and chromite in the serpentines at Dun Mountain has already been mentioned. Native copper is found in serpentine in Cornwall, New South Wales, and many other parts of the world.

Large masses of native copper, associated with silver, are found in amygdaloidal diabase at Lake Superior.

In 1879, Prof. S. H. Cox discovered, in the Manukau district, a number of dykes of andesite, which, near their borders, were found to contain small grains of native copper, finely disseminated throughout the igneous matrix.[6] The dykes are intruded in volcanic breccias of probably later Miocene age.

Platinum Metals.—Platinum has only been found in a few cases in the matrix *in situ*, and in most cases in basic or ultra-basic rocks. In the Ural Mountains, it occurs as grains in peridotite and serpentine.

The bed-rock of the Vyzaj and Kaiva rivers, on the western flanks of the Urals, consists of olivine-gabbro, containing disseminated grains of platinum, but not apparently in payable quantities.

An olivine rock was discovered in 1893, at Goroblage-datsk, on the western side of the Urals, containing chromite and platinum, the latter at the rate of 14 dwt. 9 gr. to the ton of rock.

Carmichael,[7] in 1902, reported the occurrence of platinum in a fine-grained dark basaltic rock.

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[1] W. Skey, *Trans. N.Z. Inst.*, vol. xxiii., p. 401, 1885.

[2] G. H. Ulrich, "On the Discovery, Mode of Occurrence, and Distribution of the Nickel-iron Alloy Awaruite on the West Coast of the South Island of New Zealand," *Quart. Jour. Geo. Soc.* London.

[3] *Comptes Rondus*, cxii. p. 171.

[4] *Am. Journ. Sc.* [4], xix. p. 319, 1905.

[5] *Loc. cit.*, p. 319.

[6] S. H. Cox, "Geology of Cape Rodney," *N.Z. Geol. Reports and Explorations*, 1879-80, p. 27.

[7] *Eng. and Min. Jour.*, New York, Feb. 12, 1902.

I. A. Pond, in 1886, discovered native platinum in serpentine at Wade, near Auckland, and in a great vein traversing propylitised andesite at the Thames goldfield.

Since the discovery of platinum in the nickel-copper sulphide ore at Sudbury, in Canada, careful analysis has disclosed the presence of the metal in minute quantity in many sulphide ores throughout the world. But in this, and all cases, where platinum occurs in sulphide beds or in veins, its occurrence is probably not the result of direct magmatic segregation.

II.—Ores formed by Eruptive After-actions.

It is manifest that the whole series of eruptive after-actions will commence at the movement of intrusion of the magma, and continue until the rocks have become completely cooled.

Igneous magmas are now admitted by petrologists to contain more or less water together with many constituents of a hydrous or gaseous character.

Hence the fusion of magmas is not believed to be pyrogenetic, that is, the result of dry heat alone, but hydato-pyrogenetic, that is, fusion by heat, in the presence of water. According to Arrhenius,[1] water renders the magma more liquid.

It has been shown by experiment that magmas which require a temperature of 3000° F. to produce dry fusion, can be fused in the presence of water at 500° F. Further, it has been shown that the presence of water aids in giving a magma fluidity. Barus[2] was able to fuse glass at 200° C. in the presence of water.

According to Arrhenius, water, in a magma, acts the part of an acid, liberating free silicic acid and free bases.

The activity of water at high temperature is very great. Barus[3] has shown that water, heated above 185 deg. C., attacks the silicates composing soft glass with remarkable rapidity; and Lemberg has proved, experimentally, that water, at a temperature of 210° C., slowly dissolves anhydrous powdered silicates.

It is probable that, at great depths, the pressure will be sufficient to hold the water in the form of a liquid, in a superheated condition.[4] At high temperatures, both water and steam possess a great capacity for dissolving mineral substances.

[1] Svante Arrhenius, "Zur Physik des Vulkanismus," *Geol. Fören. Förh. Stockholm*, 1900.

[2] C. Barus, *Am. Jour. Sci.*, vi. p. 270, 1898.

[3] C. Barus, "Hot Water and Soft Glass in their Thermodynamic Relations." *Am. Jour. Sci. IV.*, vol. ix., 1900, p. 161.

[4] C. R. Van Hise, "Some Principles controlling the Deposition of Ores," *Trans. American Institute of Mining Engineers*, vol. xxx. p. 27.

Contrary to the common belief, Oetling[1] found that when a magma is once molten the pressure of 200 or 300 atmospheres tends to keep it molten longer than in ordinary conditions.

(*a*) **Solfataric** (*i.e.* formed by thermal solutions, aided by steam and gases).—It is well known that, during and after volcanic eruptions, there are emitted enormous volumes of steam, also hydrogen sulphide, sulphur dioxide, carbon dioxide, as well as compounds of chlorine, fluorine, and boron.

These gaseous and aqueous emanations come from the same source as the igneous magma, accompany the magma in its ascent, and may possibly be one of the contributing causes of the eruption.

Volcanic phenomena can be studied in many parts of the world, but perhaps nowhere with more advantage than in New Zealand. In the volcanic region of the North Island, there are thousands of square miles in which volcanic activity can be seen in every stage and phase.

There are active, intermittent, and extinct volcanoes, besides innumerable geysers, fumaroles, and hot springs—active, decadent, and dead.

The active and intermittent volcanoes discharge their lavas and fragmentary matter from single pipes, or from lateral vents apparently connected with the main pipe; and from fissure-rents.

The volcanic eruption, at Rotomahana, in 1886, was from a fissure-rent, over 6 miles in length, extending from the summit of Mount Wahanga southward into the basin of Lake Rotomahana, and thence across the rhyolite plateau to Lake Okaro.[2]

The whole length of the rent was the scene of great activity for some weeks after the first great outburst.

In New Zealand, the geysers, hot springs, and fumaroles occur in isolated groups, or along a line of fissure, which often runs along the floor of a valley, or lower flanks of a range of hills.

The geysers and hot springs deposit siliceous and calcareous sinters, mostly the former; and the fumaroles, native sulphur. Everywhere the air is pervaded with the smell of sulphur dioxide (Frontispiece).

The solfataric action is active, waning, or dead. With the latter, the vents are closed up by siliceous encrustations.

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[1] Tscher, *Min. u. Petrog. Mitth.*, xvii. p. 33, 1897.

[2] Sir James Hector, "On the Recent Volcanic Eruptions at Tarawera," *N.Z. Reports of Geol. Explorations*, 1886-87, p. 243. Professor F. W. Hutton, *Report on the Tarawera Volcanic District;* Wellington, 1887. S. Percy Smith, *The Eruption of Tarawera;* Wellington, 1886. Professor A. P. Thomas, *Report on the Eruption of Tarawera;* Wellington, 1888.

Where the hot springs overflow on the surface, they form thick mushroom-shaped mounds of silica. The silica is sometimes soft and porous, and often dense, hard, and chalcedonic.

In all cases, the hot springs and geysers are grouped around the volcanic vents, and along fissures in lavas near the point of emission.

In the Hauraki gold-mining area, which adjoins the northern end of this volcanic region, the country-rocks consist of a vast pile of andesitic lavas, tuffs, and breccias of Miocene age, resting on slaty shales and greywacke of probably Triassic age.

The gold-bearing veins traverse both the andesites and tuffs, but are only productive in the former. They are fissure-veins; but, strictly speaking, they do not conform to the usually accepted definition of a true fissure-vein, since they are generally confined to the igneous rock-formation.

Near the borders of the andesites, the veins are small and unimportant, and generally die out when they reach the underlying basement rock. On the other hand, the larger and more productive veins are grouped around the old vents, and have been found to descend as deep as mining operations have followed them. There seems to be no reason why they should not descend to great depths.

The country-rock, on the walls of the veins, is propylitised to a moderately hard gray rock. When two or more veins run parallel with each other, as they do in all the Hauraki mining centres, the country-rock between the veins is often entirely altered, or propylitised.

In the Thames district, the distance between the numerous parallel veins which traverse the goldfield seldom exceeds 200 yards, and in almost every instance the veins are separated from each other by a narrow belt of hard unaltered andesite. These hard bands or *bars*, as the miners term them, possess the same general strike and dip as the veins, and in cross-section present the appearance of lenticular and hourglass-shaped masses. They vary from a few feet to 30 yards in width.

The country-rock has been found to be propylitised down to a depth of nearly 1000 feet below sea-level, which is the greatest depth reached by mining operations up to the present time.

The propylitisation of the andesites is not widespread, but confined to small areas grouped around the old volcanic vents. Away from the eruptive centres, the andesites have suffered surface decomposition, but are not propylitised.

The propylitisation was apparently effected by hot mineral waters circulating in fissures which are now filled with vein-matter. From these fissures the mineralised waters acted on the rock on each wall; and where the fissures were near each other, the metasomatic agencies, operating from one fissure, met those coming from the other. Where the processes of alteration did not meet, narrow, irregular, sheet-like masses of unaltered rock—the bars of the miners—were left between the vein-fissures.

At Waihi, and surrounding districts, the veins are principally composed of chalcedonic quartz, possessing all the characteristics of solfataric origin. Some of the larger lodes can be traced on the surface for a distance of 16,000 feet, but the length of the majority is under 5000 feet.

Besides the veins having linear extension, there are many huge mushroom-shaped masses of chalcedonic quartz, closely resembling in form the siliceous deposits now forming in the volcanic regions around Rotorua and Lake Taupo.

At Kuaotunu and Great Barrier Island there are many of these mushroom-shaped deposits, in some cases covering hundreds, in others, thousands of acres. At Kuaotunu they are more or less circular in shape, and seldom exceed 20 feet in thickness.

At Great Barrier Island, the largest deposit is of an unusual character.[1] It is nearly 2 miles long, half a mile wide, and from 50 to 700 feet thick.

The pipe is completely filled with mineral matter. It has been intersected in four mines, in a distance of a mile, and opened up by levels for many hundreds of yards. It varies from 12 to 40 feet in width, and is filled with very dense banded chalcedonic quartz, in which iron and silver sulphides are sparingly distributed.

The evidence furnished by the mine workings implies that the overlying mushroom or umbrella of quartz was deposited on the surface from thermal waters issuing from a fissure in the andesite.

The molybdenite deposits, at Jeff's Camp, in the Hodgkinson goldfield, in Queensland, are described by W. E. Cameron[2] as roughly circular, or oval-shaped outcrops of quartz, or blows, carrying wolfram and native bismuth.

The blows, when followed down, develop into irregular pipe-shaped masses, surrounded on all sides by granite, which is the country-rock. When the quartz is extracted, there remain only empty pipes or vents.

These pipe-like ore-bodies possess a peculiar interest from a genetic standpoint. They appear to closely resemble the siliceous pipes formed in rhyolite by the hot springs in the Rotorua

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[1] J. Park, "The Geology and Veins of Hauraki Goldfields," *Trans. N.Z. Institute Mining Engineers*, vol. i. p. 137, 1897.

[2] Walter E. Cameron, "Wolfram and Molybdenite Mining in Queensland," *Queensland Geol. Survey Report*, No. 188, p. 7, Brisbane, 1904.

volcanic region, and the mushroom-shaped quartz-blows at Kuaotunu.

Several of the massive deposits of chalcedonic quartz at Waihi are stated by Frank Rutley to be replacements of the andesite country-rock.[1]

A similar replacement of andesite by silica is described by Spurr as occurring at Monte Cristo district, in Washington.[2] He mentions that the silicification has proceeded until most of the rock is made up of quartz, which, he says, varies from coarsely to very finely crystalline in structure, and contains sulphides, chiefly blende, pyrites, and chalcopyrite in lenses of ore concentrated along joint-planes, bedding-planes, and contacts.

Spurr continues, "Thus we have a complete and gradual transition from andesite to a sulphide ore, with a quartz gangue, by the progressive replacement of the original materials by silica and metallic sulphides."

In 1894 and 1896, the author made an exhaustive examination of the Hauraki andesites for gold and silver.

The samples, subjected to examination, were selected *in situ.* The analyses were conducted by the cyanide test, on samples ranging from two to five pounds in weight. The pulverised material was leached with a 0·3 per cent. aqueous solution of pure potassium cyanide for seventy-two hours.

The cyanide solutions and washings were evaporated, fluxed with pure litharge, and the resulting button of lead cupelled. Simultaneous tests were made on pure substances, so as to check the results.

All the andesites were found to contain gold at the rate of 1½ gr. per ton, and silver varying from 3 gr. to 30 gr. per ton of rock.

The augite-andesite, at 3000 feet from the mouth of the Moanataiari tunnel, contained 1½ gr. of gold and 3 gr. of silver to the ton; and the hypersthene-augite-andesite, from the waterfall, in Waiotahi Creek, near the Fame and Fortune mine, contained 1½ gr. of gold, and 30 gr. of silver.[3]

A petrological examination of the rocks showed that the felspars were often kaolinised, and the pyroxenes generally much altered.[4] The samples were selected from the least altered rocks obtained, and in no case did they contain visible pyrites.

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[1] J. Park and F. Rutley, "Notes on Rhyolites of the Hauraki Goldfields," *Quart. Journal Geol. Soc.*, London, lv., 1899.

[2] J. E. Spurr, *U.S. Geol. Survey Twenty-Second Annual Report,*" 1900–1; Part II. "Ore Deposits," p. 833.

[3] J. Park, "The Geology and Veins of Hauraki Goldfields," *Trans. New Zealand Inst. M.E.*, 1897, p. 52.

[4] J. Park, "Some Andesites from the Thames Goldfields," *Trans. New Zealand Institute*, vol. xxxiv., p. 435.

The evidence is not conclusive that the gold and silver are primary constituents. Whatever the source of the gold may be the author is inclined to agree with Percy Morgan[1] that the quantity of gold and silver in the veins is too great to be accounted for by the traces existing in the country-rock.

At Te Aroha, near the boundary of the great Central Volcanic Region, there are, in the andesites, hot springs; 20 miles distant, soda-water springs; and at the Thames, 10 miles further north, gas-springs, which discharge enormous volumes of carbon dioxide.

In the mines in the north end of the field, the CO_2 issues with great force from cracks and fissures in the rocks.

The mine-shafts are situated near the foreshore, and descend to depths varying from 500 feet to 900 feet below sea-level. In close, muggy weather in summer, with a low barometer, the gas rises in the mines, and flooding all the workings, drives the miners before it. Sometimes the gas rises up to the collar of the shafts, and overflows at the surface.

Notwithstanding the special precautions employed to effect ventilation, and to warn the men of danger, several fatal accidents have taken place in the past thirty years.

In the Big Pump Shaft, the CO_2 escapes with such force as to cause violent boiling all over the surface of the water in the well. The depth of the shaft is 640 feet, but the workings are flooded up to the 500 feet level, in consequence of which the gas escapes against a head of 150 feet, equal to a pressure of 65 lb. per square inch.

The pump has been raising water from this shaft for over a quarter of a century, at the rate of 750 gallons per minute. The water is so highly charged with gas as to often cause trouble in working the pumps. The commotion at the surface of the water at the 500 feet level is caused by the escape of the gas which is not dissolved by the water.

The Hauraki veins are manifestly of solfataric origin.

At Waihi, Kuaotunu, and Great Barrier Island, there are huge veins of quartz, mostly chalcedonic, many of which are still capped with wide, mushroom-shaped "quartz blows." In many cases the mushrooms of quartz have been partly or entirely removed by denudation.

The presence of timber in mineral veins seems to point to a time when the vein-fissure was an open channel communicating at some point of its course with the surface, as hot springs do at the present day.

Posepny mentions the remarkable occurrence of tree-stems

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[1] Percy Morgan, "Notes on the Geology, Quartz Reef, and Minerals of Waihi Goldfield," *Trans. Austral. Inst. M.E.*, vol. viii. p. 164, 1902.

charged to galena from the Vesuvian mine, Freihung, in Bavaria. In these the fibre and annular rings could be easily recognised, being extremely plain on polished surfaces.[1]

Mr R. D'Audrèmont (*Bull. de la Soc. Géol. Belgique*) states that in a pitchblende mine at Joachimsthal, in Bohemia, a piece of carbonised wood, from a deciduous plant, was found in a fissure filled with volcanic tuff at a depth of 915 feet.

In the tuffs associated with the Hauraki gold-bearing andesites, masses of wood, partly or wholly silicified and spangled with nests and veins of iron pyrites, are of common occurrence.

The Martha lode, and its numerous ramifying branches, and the Silverton, Union, and Amaranth lodes, at Waihi, are all contained in an area of about a square mile. The huge lodes, wide zones of silicified andesite and extensive propylitisation of the andesite, prove that Waihi was an area of intense hydrothermal activity some time prior to the eruption of the later rhyolite flows, which now form the plains, and wrap around the Martha and Silverton veins.

The propylitisation has already been shown by the Waihi mine workings to extend to a depth of nearly 800 feet below present water-level, that is, some 400 feet below sea-level. Obviously, the alteration of the andesite was due to the action of ascending and laterally moving thermal waters.

At Thames and Coromandel some of the most productive veins do not reach the surface of the enclosing rock; and the mine workings at Waihi have disclosed a similar feature in connection with a few valuable veins in the Waihi Company's property.[2]

In 1898, Captain F. W. Hutton, F.R.S., as the result of a petrographical examination of the Thames mining district, concluded that the veins were of hydrothermal origin.[3]

T. A. Rickard, a well-known American geologist, who examined the same goldfield in 1891, when discussing Professor Posepny's paper on "The Genesis of Ore Deposits," describes the characteristic features of the district, with the view of adducing additional evidence of the association of thermal springs and later eruptive rocks.[4] He states that his examination of the ore-occurrences and vein-structure, though incomplete, led him to conclude that the

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[1] Professor Franz Posepny, "*The Genesis of Ore Deposits*," p. 129, 1901.

[2] P. C. Morgan, "Notes on the Geology, Quartz Reefs, and Minerals of the Waihi Goldfield," *Trans. Austr. Institute of Mining Engineers*, vol. viii. p. 168, 1902.

[3] F. W. Hutton, "On the Rocks of the Hauraki Goldfield," *Trans. Aust. Assoc. Adv. Sc.*, vol. viii. p. 245, 1888; and "Source of Gold at the Thames," *N.Z. Journal of Science*, vol. i. p. 146.

[4] T. A. Rickard, *The Genesis of Ore Deposits*—Discussion, New York, 1901, p. 222.

deposition of the gold and its associated minerals had followed certain lines of altered country-rock, which had been exposed to the effects of dying but lingering solfataric agencies.

The Ohaeawai Hot Springs quicksilver deposits, north of the Hauraki peninsula, are of great importance, on account of the evidence which they furnish in connection with the genesis of solfataric ore-deposits.

The basement rocks consist of lower Mesozoic shales and sandstones overlain by greensands of lower Tertiary or upper Cretaceous age, which are covered with flows of basalt and beds of scoriæ. It is agreed by all geologists that the basalt constitutes the youngest rock-formation in the district.

The surrounding country is studded with old craters; and there is everywhere evidence of former intense volcanic activity.

The hot springs, around which the quicksilver deposits are clustered, are situated about two miles south-east of Lake Omapere, which itself occupies the site of an old crater.

They occur along the edge of a flow of basalt, which is overlain at this point by deposits of calcareous and siliceous sinter and solidified siliceous and carbonaceous muds, through which sulphur and cinnabar are finely disseminated.

There are also deposits of pyrites with or without cinnabar, in some cases containing traces of both gold and silver.[1] The sinters also contain gold and silver.

The ground around the springs is generally very hot; and all attempts to develop the quicksilver deposits have been frustrated by the large volumes of hot water encountered at shallow depths below the surface.

The district has been examined at different times by Captain Hutton, Sir James Hector, A. M'Kay, and the author; but the best description is that of Andre P. Griffiths, who conducted extensive prospecting and mining operations there in 1895 and 1898.

The mining operations and borings disclosed many important details, which could not be gathered from a surface examination.

The iron pyrites occurs in masses near the basalt, and also filling cracks and fissures in that rock. The thickness of the masses varies from 3 inches to 3 feet, but their other dimensions are extremely irregular.

Close to the pyritic masses there is a hard, white siliceous sinter, from 8 to 10 inches thick, which Griffiths found to contain gold and silver in places. One assay of the sinter gave a

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[1] Andre P. Griffiths, "The Ohaeawai Quicksilver Deposits," *Trans. New Zealand Institute Mining Eng.*, vol. ii. p. 48.

value of £3 per ton, but unfortunately the proportions of the gold and silver are not given.[1]

The cinnabar generally occurs lining small cavities and cracks in the solidified muds and sinters surrounding the original fissures in the basalt. It also occurs impregnating the sinter in an extremely finely divided form.

Sulphur occurs throughout the sinter in larger proportion than either the cinnabar or pyrites.

The hot springs give off large quantities of H_2S, and occasionally a little steam. The gas escaping through the water of the pools and small streams is partially oxidised liberating sulphur, which imparts a milky white colour to the pools, locally known as white lakes.

The beaches of the so-called white lakes consist of sulphur, mixed with magnetic ironsand, and a small proportion of alum. Sulphur is also being sublimed, at the vents or openings in the rocks, from which H_2S and SO_2 gases escape.

The prospecting work conducted by Griffiths disclosed some interesting features.

A deposit of cinnabar and pyrites crops out at the foot of the hills, to the south-west of the main deposits. A shaft was sunk near it, and cut the lode at a depth of 35 feet. The ore was 2 feet thick, and consisted of small crystals of pyrites cemented by cinnabar. At this depth there was a strong evolution of H_2S, and the heat of the rocks increased so rapidly with the depth that mining was extremely difficult.

It is noteworthy, as showing the recent formation of the cinnabar, that near the outcrop of this lode was found the charred trunk of a tree, partially embedded in hard siliceous mud. The trunk and roots of the tree were coated with a thin film of cinnabar, as also were some pieces of fossil kauri gum found near the roots.

In a small trench sunk over a fumarole, the temperature of the rock at a depth of 10 feet was found to be 185° Fahr.

No. 1 bore-hole, cased with 3-inch piping, was put down to a depth of 104 feet, where it encountered the edge of the basalt. At the same time it struck a fissure, from which hot mud was projected a height of 60 feet above the surface for about forty-eight hours.

The mud was succeeded by boiling water, charged with H_2S gas, which was found to issue at a pressure of 30 lb. per square inch.

Griffiths further mentions that the richest deposits of cinnabar were found in close proximity to the hottest fumaroles, and that

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[1] Andre P. Griffiths, *loc. cit.*, p. 50.

at very shallow depths a temperature was soon reached which precluded mining operations being carried on.

The Ohaeawai Hot Springs cinnabar deposits, although never likely to be turned to economic account, are of great scientific importance from the light which they throw upon the processes of ore-formation by volcanic after-actions.

The deposits are still in process of formation, and metallic sulphides have been, and are still being, deposited in underground fissures, and at the surface, together with the sinters, which form the matrix.

The hot springs and fumaroles owe their existence to the eruption of the basalt, but the basalt is manifestly not the source of the metals. The source may not be deep seated, but that it exists at some distance below the flow of basalt is almost certain.

The waters of the Ohaeawai Springs were found by Captain Hutton, in 1870, to contain zinc, manganese, silica, free sulphur, and hydrochloric acids, but no traces of mercury.[1]

A sample of the water analysed by W. Skey, in 1896, gave the following results :—

	Grains per gallon.
Protoxide of iron, . . .	2·23
Lime, ...	5·97
Magnesia, ...	1·15
Silica, ...	3·10
Sulphuric acid, . . .	13·60
Hydrochloric acid, . . .	66·91
Sulphuretted hydrogen, . .	traces
Alkalies, ...	41·66
Ammonia, ...	traces
Organic matter, . . .	traces

Abundant evidence of the hydrothermal origin of veins traversing eruptive rocks is also obtainable in Europe and America.

In several of the mines in the Comstock lode, ascending thermal waters were encountered in the deep workings, and seriously impeded mining operations.[2]

The water, which flooded the Gold Hill mines, issued from a bore-hole in the Yellow Jacket shaft, at a depth of 3080 feet. It had a temperature of 170° F., and was heavily charged with hydrogen sulphide.[3]

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[1] F. W. Hutton, "On the Occurrence of Native Mercury near Pakaraka, Bay of Islands," *Trans. New Zealand Institute*, vol. iii. p. 251, 1871.

[2] Clarence King, *U.S. Geological Exploration of 40th Parallel*, 1879, p. 87.

[3] George F. Becker, "Geology of the Comstock Lode," *U.S. Geol. Survey*, 1882, p. 230.

Baron von Richthofen,[1] who examined the Comstock lode, at a time when no abnormal temperature was noticeable, ascribed the origin of the lode to earlier solfataric action.

The quicksilver mines at Sulphur Bank, in California, furnish important evidence in relation to the genesis of ore-deposits.

At this place the basement rocks are slate and sandstones, overlain by a freshwater formation, which in turn is capped by a flow of basalt. The geologic features are almost identical with those existing at Ohaeawai.

The sandstones and slates are broken and fissured in such a way as to form a breccia. The interspaces are filled partly with a still soft or already indurated siliceous paste, containing finely disseminated metallic sulphides, and partly with cinnabar, for the most part in coherent crusts.[2]

In the same mine the basalt is reduced to a porous mass, and traversed by irregular fissures, filled with sulphur and cinnabar.[3]

Hot mineral water and gases, carrying H_2S, force their way through the interstices of the deposit in the fissured sandstones and slates.

The silica deposits are found in all stages of consolidation, from a gelatinous mass to chalcedony, and alternate with layers of metallic sulphides, consisting of cinnabar and pyrites.

Unfortunately no information is obtainable as to the nature of the freshwater formation lying between the Cretaceous sandstone and basalt.

According to Becker, the hot water is rich in chlorides, borax, and sodium carbonate. The gases liberated from the water consisted of 893 parts of CO_2, 2 parts of H_2S, 79 parts of marsh gas (CH_4), and 25 parts of nitrogen in 1000 parts.

According to Dr Melville, the marcasite, associated with the cinnabar, contained traces of gold and copper; and in the efflorescence from the mine workings, Becker detected traces of cobalt and nickel.

In the upper zone only sulphur was found; lower down sulphur and cinnabar; and in depth, cinnabar and pyrites occurring upon or within deposits of silica.

The Steamboat Springs, in Nevada, furnish equally important

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[1] F. von Richthofen, *The Comstock Lode: Its Character and Probable Mode of Continuance in Depth*, San Francisco, 1866, p. 54.

[2] J. Le Conte, "On Mineral Veins now in progress at Steamboat Springs compared with the same at Sulphur Bank," *Am. Jour. of Science*, vol. xxv. p. 404.

[3] Professor F. Posepny, "The Genesis of Ore Deposits," *Trans. American Inst. Mining Eng.*, vol. xxiii. p. 197.

evidence of vein-filling by hot-spring action. They have been fully described by Le Conte,[1] Becker,[2] and other writers.

In a valley surrounded with eruptive rocks and underlain by altered sedimentaries, believed to be of archæan age, thermal springs issue from several points from north and south fissures.

The floor of the valley is covered, in places, with a sheet of calcareous sinter, in which there are many fissures, here and there still open, but mostly closed by the deposit of silica on their walls.

From some of the springs hot vapours and gases, chiefly CO_2 and H_2S, still issue.

Becker found, in the mineral water, small amounts of mercury sulphide and sodium sulphide.

About a mile to the west of the main group there are similar fissures yielding steam and CO_2. In the sinters of these occur several metallic sulphides.

Becker analysed the filling of several fissures, and found, besides hydrated ferric oxide, lead, copper and mercury sulphides, gold and silver, and traces of zinc, manganese, cobalt, and nickel.

The occurrence of metallic sulphides in the sinters at Sulphur Bank, Steamboat Springs, and Ohaeawai Hot Springs; the mushroom-capped lodes at Waihi and Great Barrier Island; the tree-stems replaced by sulphides, found in veins at great depths below the present surface, afford conclusive evidence of the filling of veins by hot ascending waters and gases in areas occupied by late eruptive rocks.

It is a notorious circumstance that ore-deposits are most common in the neighbourhood of extended zones of igneous rocks, as in Hungary, Transylvania, Nevada, Colorado, and New Zealand, where the vein-bearing rocks are principally andesite, phonolite, and trachyte. In other rocks veins are fewer and more scattered.

For veins in the altered later eruptives Lindgren suggests the name propylite-veins, but it is doubtful whether the genetic difference between them and true fissure-veins is sufficiently marked to justify the distinction. Moreover, the roots of propylite-veins would be difficult to distinguish from fissure-veins connected with a plutonic intrusion.

Professor Suess,[3] speaking of the importance of the rôle played by the waning phases of volcanic phenomena in the formation of mineral-veins, says, "Hot springs may be taken as

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[1] J. Le Conte, "On Mineral Veins now in Progress at Steamboat Springs compared with the same at Sulphur Bank," *Am. Jour. of Science*, vol. xxv. p. 424.

[2] G. F. Becker, "Geology of the Quicksilver Deposits of the Pacific Slope," *U.S. Geol. Survey*, Washington, 1888, p. 331.

[3] Professor Edward Suess, Lectures, *The Geographical Journal*, vol. xx., Nov. 1902, p. 520.

the latest phases of a whole series which led up to the present deposits of ore."

Action of ascending Alkaline Waters.—The waters which rise to the surface in the region about Lake Rotorua are alkaline, neutral, or acid. Shafts and bore-holes put down in the pumice and rhyolites, which constitute the great bulk of the rocks in this area, have shown that the alkaline waters come from a deep-seated source, while the acid waters have quite a superficial origin. This has led to the erroneous conclusion that all the waters have not a common origin.

Lake Rotorua is an old crater-lake, the southern shores of which are crusted over with deposits of sinter formed by the existing hot springs. Below the sinter there is a thick deposit of pumice, and below the pumice flows of rhyolite generally pumiceous or pisolitic.

In the pumice there are many deposits of finely disseminated marcasite which were apparently formed by solfataric action at some earlier date, in the way that the deposits of pyrites and cinnabar are now being formed at Ohaeawai Hot Springs, north of Auckland. The hot ascending alkaline chlorinated waters become partially or wholly oxidised into sulphates by contact with the decomposing iron sulphide with formation of free sulphuric and hydrochloric acids, and liberation of sulphuretted hydrogen and sulphurous acids. In this way the ascending alkaline waters that happen to come in contact with masses of pyrites become oxidised in the superficial layers of the pumice, and rise to the surface as neutral or acid springs according to the degree of oxidation they have undergone.

Thus, within a small area we have the singular phenomenon of waters that reach the surface in all conditions ranging from the highly alkaline to the extremely acid according to the degree of oxidation of the contained salts.

The composition[1] of the salts in the alkaline waters of Rachel Spring in grains per gallon is as follows:

Sodium chloride, . . .	69·43
Potassium chloride, . . .	3·41
Lithium chloride, . . .	traces
Sodium sulphate, . . .	11·80
Silica, ...	5·87
Sodium silicate, . . .	18·21
Calcium silicate, . . .	4·24
Magnesium silicate, . . .	1·09
Oxides of iron and alumina, .	2·41
Total, . .	116·46

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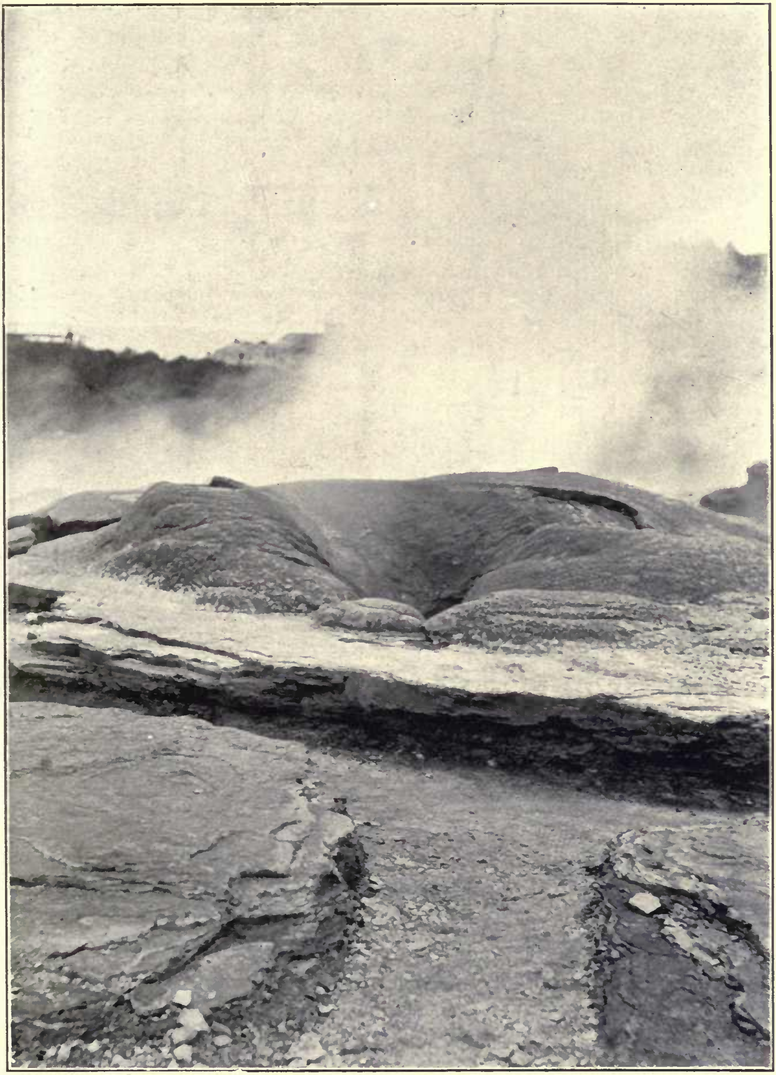
[1] *The Mineral Waters and Health Resorts of New Zealand,* Dr Wohlmann, Part I., 1904, p. 39.



Photo, Dr Wohlmann.]

GEYSER-CRATER AT WHAKAREWAREWA, NEW ZEALAND, SHOWING SILICEOUS CRUSTIFICATION.

Also sulphuretted hydrogen and carbon dioxide not estimated.

In the majority of cases, the alkaline springs deposit layers of silica on the walls of the vent and at the surface, the latter often forming large mushroom-shaped masses.

The composition of the waters of the Priest hot spring, which may be taken as typical of the acid waters, is as follows :—

	Grains per gallon.
Sulphate of soda,	19·4
,, ,, potash,	traces
,, ,, lime,	7·41
,, ,, magnesia,	3·03
,, ,, alumina,	21·67
,, ,, iron,	1·24
Sulphuric acid (free),	22·12
Hydrochloric acid (free),	3·65
Silica,	18·41
Total,	96·77

The temperature of the alkaline waters, as their deep-seated origin would suggest, is very high, varying from 180° to 212° Fahr.; while that of the acid waters is low, commonly ranging from 98° to 110° Fahr.

The sinters are found of all degrees of hardness. They are soft, spongy, and vesicular, or hard and compact. The sinter encrusting the walls of the fissures and pipes from which the waters escape at the surface is generally hard and chalcedonic and arranged in layers which often present a fine ribbon-structure (Plate II.). Hand specimens of the harder sinters cannot be distinguished from much of the ore found at the outcrop of the Martha lode at Waihi. In places the sinters contain finely disseminated marcasite and a trace of gold and silver.

Around Rotorua we can see ore-deposits of the solfataric class still in process of formation on a scale of considerable magnitude. Of the genesis of the ascending alkaline waters nothing is known at present.

(*b*) **Fumarolic.**—In this class are grouped deposits of sulphur, ferric chloride, cupric oxide, and boron salts, formed by the escape of steam and gaseous emanations in volcanic regions. Of these, sulphur and boric acid alone are of economic value.

Boron salts are common in many volcanic regions. The entire production of boric acid from Italy is obtained from the steam fumaroles in the provinces of Pisa and Grosseto.

Sulphur is sublimed from fumaroles and craters by the mutual reaction of hydrogen sulphide and sulphur dioxide. It is found impregnating vesicular lavas, tuffs, and siliceous sinters, and mixed with volcanic muds and gypsum deposits.

The most important known deposits of sulphur occur in Italy, Spain, Hungary, Chili, Mexico, Japan, United States, and New Zealand.

The sulphur-deposits of Italy occur in veins or lenticular masses, in rocks of Miocene age, chiefly in the provinces of Caltanisetta and Girgenti.

In Nevada, the sulphur-bearing rock occurs in beds lying between limestone and magnesian rocks.

In Utah, the sulphur occurs associated with gypsum, near an old crater.

At Tikitere, in New Zealand, there are extensive deposits of sulphur in an old crater. A large proportion of the sulphur is the black amorphous variety. The heat of the fumaroles and hot springs is too great to permit the excavation of the sulphur to a greater depth than 6 or 8 feet.

At White Island, the deposits of sulphur occur in and around the crater-lake, mixed with gypsum. The crater-water is hot, and highly charged with free hydrochloric and sulphuric acids. The gypsum is deposited in crystalline incrustations, on the sides and floor of the crater-lake. The source of the lime has not yet been determined; but the supply must be constant, as gypsum is being deposited continuously.

The sulphur is deposited in the water from gas-springs, which are seen bubbling everywhere in the floor of the lake; and also from fumaroles around the margin of the crater.

(*c*) **Contact Metamorphic Deposits.**—A molten magma tends to effect changes in the rocks with which it comes in contact. In the case of overflow magmas, the thermal changes are generally trifling, and in many cases hardly appreciable. Even magmas that have cooled in rents in sedimentaries at shallow depths, have not always caused great changes in the enclosing rock.

The greatest alteration will, naturally, take place in the case of magmas that do not reach the surface, but cool slowly under great pressure.

The greater the mass of the intrusive magma, the slower will be the rate of cooling; and the slower the rate of cooling, the longer will the adjacent rocks be heated.

The rate of cooling will be mainly dependent upon the mass of the intrusion, the distance from the surface, and the relative thermal conductivity of the adjacent rocks.

The changes effected in the country-rock by the intrusion of an igneous magma will be mechanical and thermal.

The intruded sedimentaries will be compressed, bent, and more or less shattered and fissured along the line of intrusion.

The magma will part with its heat by slow radiation into the adjacent rocks.

The occluded steam and gases in the magma, together with the steam generated from the water contained in the sedimentaries, will pass into and permeate the latter, and cause a molecular rearrangement of the constituent minerals, resulting in what is termed contact-metamorphism.

As the igneous magma and the heated sedimentaries cool, they will contract in area, and when the temperature normal to the depth has been reached, the contraction will tend to cause the two rocks to shrink from each other, resulting in the formation of cavities along the line of contact.

The contraction or decrease in volume of a molten magma in solidifying, according to the experiments of Barus,[1] Forbes,[2] Delesse,[3] and Cossa,[4] amounts to 4 or 6 per cent. of the original volume.

Above a temperature of 365° C., and a pressure of 200 atmospheres, water, and all more or less volatile compounds, will exist as gas.

Aqueous vapours above the critical temperature and under great pressure, will react as strongly upon the cooling magma as upon the adjacent rocks. They will possess a solvent power, which will be greatest at the depth where the highest temperature and pressure are reached. The pressure will cause the heated steam and gaseous emanations carrying the heavy metals to permeate the bedding planes of the sedimentaries, and fill all accessible cracks and fissures. In this way bed-impregnation may be effected, and even ore-bodies formed at points some distance from the genetic eruptive magma.

A decrease in the temperature and pressure will cause the least soluble substances to be deposited; and as the temperature and pressure continue to diminish, the dissolved substances will be thrown out of solution in the inverse order of their solubility.

It is manifest that the later phase of the eruptive after-actions will represent, in a modified form, the waning effects of solfataric action. The deep-seated conditions will also favour the action of metasomatic processes in the zone of anamorphism, and veins will be formed, some of which may rise to the surface.

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[1] Barus, *Phil. Mag.* [5], xxxv. p. 173, 1893.

[2] Forbes, *Chem. News*, Oct. 23, 1868.

[3] Delesse, *Bull. Soc. Géol. France* [2], iv. p. 1380, 1847.

[4] Zirkel, *Lehrbuch d. Petrographie*, i. p. 681, 1893.

It is probable that the circulation of the heated mineralised solutions, in the later phases, will tend to effect a redistribution of the ores and minerals deposited in the earlier stages. In some cases, the ascending waters and gases may reach the zone of surface circulation, and mix with the meteoric waters, which may then reappear as hot springs, forming ore-bodies and veins not directly in contact with the eruptive magma.

Weed and some other writers have made an attempt to subdivide contact-metamorphic deposits into groups, depending mainly upon the mode of occurrence. But the form and mode of distribution may be due to accidents of density or porosity, composition and hydrous condition of the rocks affected, rather than differences in genetic formation.

Moreover, the mass of the magma, the weight of superincumbent rocks, the amount of heat and subsequent contraction, and phase of the after-action, are all doubtless contributing factors in connection with the form and distribution of the heavy metals.

Masses of ore, occurring as contact-deposits, fissure-veins, and bed-impregnations, in the zone of metamorphism, may all be traced to the same genetic causes.

Professor L. de Launay, of Paris, supports the views of the school of De Beaumont and Daubree in respect of the primary influence of volatile mineralisers emanating from eruptive magmas. The emanations, he contends, must have prepared the way, by introducing into the enclosing rocks, or simply by depositing in the vein-fissures, constituents such as sulphides, fluorides, chlorides, etc., which, subsequently dissolved anew by the circulation of superficial waters, have rendered the latter essential aid in the processes of alteration.[1]

The extent of contact-metamorphism effected by the granite intrusions of Albany, in New Hampshire, was fully investigated by Hawes.[2] His analyses showed a progressive series of changes in the schists as they approach the granite. The rocks are dehydrated, boric and silicic acids have been added to them, and there appears to have been an infusion of alkali at the time of contact. He regarded the schists as having been impregnated by hot vapours and solutions emanating from the granite.

Contact-deposits frequently lie at the boundary between the eruptive and the country-rock; also at variable distances from the eruptive, but never outside the zone of metamorphism.

More particularly, contact-ores occur in limestones, marly and clay-slates, and are accompanied by the usual contact-minerals, garnet, vesuvianite, scapolite, wollastonite, augite, mica, hornblende, etc., and in clay-slate by chiastolite, etc.

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[1] L. de Launay, *The Genesis of Ore Deposits*, 1901, Discussion, p. 616.

[2] G. W. Hawes, *Amer. Journ. Sci.*, xxi., 1881, p. 21.

Contact-ores are principally magnetite and specular iron, but sulphides of copper, lead, and zinc often occur.

Pyritic contact-deposits are typically represented by those of Vegsnas, in Norway, Rio Tinto, Tharsis, and San Domingo, in Spain.

The pyritic ore-mass in Mount Lyell Mine, in Tasmania, is generally described as a replacement contact-deposit, although its geologic occurrence does not strictly conform to the common definition of such a body. Professor Gregory describes it as a boat-shaped mass, lying between talcose schist and conglomerates.[1] The mine-workings have shown that it gradually tapers downwards from the outcrop, being cut off with a rounded base by a great thrust-plane (*loc. cit.*).

There are no eruptives in actual contact with the ore-body, but dykes of diabase and other igneous rocks occur in the district, at no great distance. The presence of these dykes, and of bands of schist, impregnated with sulphides, forming fahlbands, would lead to the belief that at one time there existed channels of communication leading from the eruptive magmas to the vein-cavities. In all probability the Mount Lyell sulphide ore-bodies and bed-impregnations were formed in the later, or solfataric stages, of eruptive after-actions.

(*d*) **Regional Metamorphic Deposits.**—To this group belong the deposits of iron-ore which occur in altered sedimentary rocks, generally of older Palæozoic age.

The iron probably existed originally as sedimentary deposits, and became concentrated and rearranged under the influence of the heat, pressure, and solutions, which caused the metamorphism of the enclosing rocks.

Examples of deposits of ore due to regional metamorphism, in which metasomatic processes doubtless took an active part, are found among the valuable magnetic deposits of Sweden and the vast specular iron and magnetite masses of Michigan.

Massive aggregates of magnetite are common in chlorite-schist and mica-schist in all parts of the globe.

Metamorphic rocks also enclose beds of iron pyrites and pyrrhotite, the origin of which is still obscure.

III.—METEORIC WATERS.

(*a*) **Chemical.**—In this group are included deposits of salt, borax, nitre, bog-iron ore, and some deposits of gypsum and manganese.

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[1] Professor J. W. Gregory, "The Mount Lyell Mining Field," *Trans. Aust. Inst. Min. Eng.*, vol. i. Part IV., July 1904, p. 281.

(*b*) **Mechanical.**—This group includes all sedimentary rocks formed by the agency of water in lakes and seas; also alluvial drifts, whether loose or compact, of river or lake origin, containing gold, tin, platinum, and gems; and ore-bearing sea-beaches deposits.

IV.—ORGANIC.

(*a*) **Vegetable.**—This group embraces all varieties of mineral fuel, ranging from peat to anthracite, also graphite, oil-shale, mineral-oil, and natural gas.

(*b*) **Animal.**—The minerals included in this subdivision are limestones, including chalk and mineral phosphates.

CHAPTER VI.

THEORIES OF VEIN FORMATION.

CONTENTS:—Eruptive Processes—Theory of Lateral Secretion—Ascension of Solutions—Summary.

THE theories which now receive the most acceptance are as follows:—

I. Eruptive processes:—
   (*a*) Magmatic segregation.
   (*b*) Eruptive after-actions.

II. Lateral secretion.

III. Ascension of solutions.

Eruptive Processes.—The importance of the rôle played by igneous rocks in the formation of ore-deposits has been specially urged in late years by Professor Vogt[1] of Christiania, Professor Kemp[2] of New York, Professor Suess[3] of Vienna, and more recently by Waldemar Lindgren[4] and W. H. Weed[5] of the United States Geological Staff.

Vogt directs renewed attention to the close relationship existing between ore-deposits and eruptive processes. Ore-deposits connected with eruptive magmas are grouped by him into two principal classes as under:—

(1) Ore-deposits formed by magmatic segregation.
(2) Ore-deposits formed by eruptive after-actions.

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[1] Professor J. H. L. Vogt, "Problems in the Origin of Ore Deposits," *The Genesis of Ore Deposits*, 1901, p. 636.

[2] J. F. Kemp, "The Rôle of the Igneous Rocks in the Formation of Veins," *loc. cit.*, p. 681; also *Trans. Amer. Inst. M.E.*, vol. xxxii., 1902, p. 681.

[3] Professor Edward Suess, Lecture, *The Geographical Journal*, vol. xx., 1902, p. 520.

[4] Waldemar Lindgren, "Character and Genesis of Certain Contact Deposits," *Genesis of Ore Deposits*, 1901, p. 716.

[5] W. H. Weed, "Ore Deposits near Igneous Contacts," *Trans. Amer. Inst. M.E.*, vol. xxxiii., 1903.

Ore-deposits belonging to the first group are infrequent, and therefore economically subordinate in importance to those of the second group. They include, according to Vogt:—

(*a*) The occurrences of titanic iron ores in basic and semi-basic eruptives.
(*b*) Chromite in peridotite.
(*c*) Sulphide deposits, including the nickeliferous pyrrhotite of Sudbury, in Canada.
(*d*) Platinum-metals in highly basic eruptive rocks.
(*e*) Copper and metallic nickel iron in serpentinised peridotite.

That sulphides can be segregated from eruptive magmas in the first concentration has yet to be proved; and it is still doubtful how far Vogt's conclusions respecting the occurrence of sulphide ore, as a product of primary segregation from a molten magma, are admissible.

In all cases metasomatic processes are said to have played an important part in the formation of these valuable deposits.

In the eruptive after-action group, Vogt includes cassiterite and apatite veins and "ore-deposits of contact-metamorphic zone."

Cassiterite deposits are everywhere connected with acid eruptives, principally granite, and occasionally quartz-porphyry and rhyolite. Partly for this reason, and partly because of the characteristic paragenesis of fluoride, borate, and phosphate minerals, he supports the common view that tin-deposits are genetically connected with granitic eruptions, and that various volatile fluorides took part in their formation.

Cassiterite veins were formed, he thinks, by *pneumatolytic processes*,[1] that is, by the action of gases and water at high temperature and pressure.

He further urges that they were formed immediately after the eruption, and before the complete cooling of the granite, one proof of which, he thinks, is the occurrence of tin-vein minerals in veins of pegmatite in the granite.

Cassiterite veins are admittedly independent of the immediately adjacent country-rock, and for this reason seem to be more nearly related to deposits of magmatic segregation than to contact-metamorphic deposits.

It is probable that the magmatic segregation of chromite in peridotite was in some cases effected by pneumatolytic agencies before the complete cooling of the magma. It is not uncommon to find chromite in vein-like masses that have the appearance of having been segregated in cavities of contraction in the pasty

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[1] Pneumatolysis is a term first used by Bunsen to describe the combined action of gases and water.

magma. As the agency of underground water cannot have been active in this class of ore-deposit, the aggregation must have been effected by metal-bearing steam and gases occluded in the igneous magma.

Pegmatite veins, while generally connected with granitic eruptions, seem to be of later formation than the cassiterite veins. They often pass into quartz and frequently possess sharp, well-defined walls which suggest their formation in shrinkage cracks by pneumatohydato-genetic agencies in the waning phases of the after-actions, developed by the progressive cooling of the eruptive magma. Teall has suggested that micropegmatite is an eutectic which crystallises at the lowest possible temperature, and represents in certain rocks the final mother-liquor from which the other minerals have crystallised out.

The different phases of after-action must necessarily merge into each other, and hence we may expect to find, as we do, tin-vein minerals and even cassiterite in veins of pegmatite.

Among ore-deposits of contact-metamorphic origin, Vogt includes the ore-bodies which occur within the metamorphosed contact-zone of deep eruptives, especially granite.

He distinguishes several types of contact-deposit. The Christiania type includes iron-ore deposits that appear to have been formed before the solidification of the granitic magma.

These ores are never found in the granite, but always in the adjacent rocks. If they had been introduced after the cooling of the magma, they would also have been deposited in the granite.

The eruptive magma is believed to be the source of the metal which is expelled in the heated steam into the surrounding rocks.

In 1902, Weed[1] proposed the following provisional genetic classification based on that of Vogt:—

I. Igneous (magmatic segregation)—
    (*a*) Siliceous.
    (*b*) Basic.

II. Igneous (emanation deposits)—
    (*a*) Contact-metamorphic deposits.
    (*b*) Veins (related to magmatic veins and division IV.).

III. Fumarolic.

IV. Gas-aqueous (pneumatohydato-genetic) deposits—
    (*a*) Filling deposits.
    (*b*) Replacement deposits.

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[1] W. H. Weed, "Ore Deposits near Igneous Contacts," *Trans. Amer. Inst. M.E.*, vol. xxxiii., 1903, p. 715.

V. Meteoric waters—
- (*a*) Underground.
- (*b*) Superficial.

In this classification the major subdivisions are based upon magmatic segregation at one end and cold aqueous deposition at the other, with intermediate groups characteristic of the different phases of eruptive after-actions.

Weed divides magmatic segregations into two groups, namely, Siliceous and Basic. The latter embraces deposits of iron, copper, etc., found at igneous borders and as dykes ; and the former, the ore-bearing pegmatites, with quartz-veins as extreme examples.[1]

This is a distinct departure from Vogt's conception of magmatic segregation. It is almost certain that the segregation of ores from basic magmas, and the formation of cassiterite and pegmatite veins, are genetically connected with the after-actions of deep-seated eruptions, and as such must, in some degree, be related and merge into each other. But this genetic connection, while it increases the difficulty of formulating a satisfactory classification, hardly justifies the subdivision proposed by Weed.

The synthetic experiments of Daubree seem to support the views of Vogt, Beck, and other observers who maintain that cassiterite and pegmatite veins are formed by gaseous and aqueous emanations, and not by direct segregation.

Gold is commonly associated with acid rocks, but it does not occur in such a manner as to suggest direct segregation. In Queensland, New South Wales, and New Zealand it is found in quartz-veins in granite and quartz-porphyry, but in these cases the veins manifestly fill contraction-cracks.

Weed strongly dissents from the view expressed by Van Hise, that meteoric waters are an important creative factor in the formation of ore-veins. He thinks, however, that primary hot ore-bearing solutions and hot vapours may rise into the zone of circulating meteoric waters, heating the latter and charging them with metallic salts and such active mineral solvents as fluorine, chlorine, and boron. He summarises his views relating to the formation of contact-deposits as follows :—

"Contact metamorphic ore-deposits occur about the margin of intrusive masses of granular igneous rock, either at the actual contact or in the zone of metamorphosed sedimentaries. The deposits of economic value occur only where strata or blocks of impure limestone have been crystallised as garnetiferous or actinolite-calcite rocks, with consequent porosity. The ore-minerals are intimately associated with these aluminous silicates,

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[1] Weed, *loc. cit.*, p. 717.

and may be either intergrown, or metasomatic replacements, or the result of interstitial filling with partial replacement. The conversion to garnet-epidote-calcite, etc., rock was complete before the consolidation of the igneous rock. The ore-minerals were introduced in gases and vapours—solfataric emanations—from the eruptive masses, of which they constitute pneumatolytic after-actions, or by hot circulating waters given off by the cooling igneous mass. This theory of the genesis being true, the deposits should extend downward in depth to the granular rock."

Professor Kemp, of New York, in a valuable paper on "The Rôle of Igneous Rocks in the Formation of Veins,"[1] maintains that the circulation of ground-water is insufficient to account for the majority of the ore-deposits in the United States. He supports the petrological view, that igneous rocks must have furnished not only the metallic contents, but a large proportion of the waters which brought the metals into their present position.

His conception of ore-formation is as follows :—

(1) Igneous rocks contain the metals and elements of the gangue minerals more abundantly than do sedimentary rocks.

(2) Igneous rocks are richly provided with vapours, which come up with them from great depths. Igneous rocks are enormous reservoirs of energy.

(3) Igneous districts, or districts of combined igneous and sedimentary rocks, are almost always the geological formation in which the veins occur.

(4) The vapours and solutions from intruded igneous rocks are pre-eminently favourable chemical reagents.

(5) Observations in deep mines, and the data from very deep wells, indicate the general absence of free water in the rocks below moderate depths, except in regions of expiring vulcanism. This is a grave objection to the conception of universal ground-water.

(6) Capillary attraction is largely an ascensive force, and of problematic existence with increasing pressure. Artesian reservoirs of themselves are unfavourable to extended circulation. There is a strange absence of the original content of water in deep-seated sediments. Standing water in abandoned shafts is strong evidence of the impenetrability of rocks.

(7) Hot springs are necessarily connected with an abnormal rise of the isogeotherms, and this can only be explained by intruded igneous rocks, or by faults or shattering.

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[1] J. F. Kemp, *Trans. Amer. Inst. M.E.*, vol. xxxii., 1902, p. 681.

The latter do not compare with the former as an efficient cause.

Theory of Lateral Secretion.—According to this theory, it is assumed that meteoric waters percolating through the country-rock, by the aid of carbon dioxide and alkalies, dissolve out certain constituents which are afterwards deposited in fissures, thereby forming mineral-veins.

The origin of the theory is unknown, but it is certain that Delius in 1770, Gerharde in 1781, and Lasius in 1789, were supporters of it, the latter basing his conceptions upon a careful examination of the veins of the Hartz mountains.[1]

In 1847, Professor Bischof, of Bonn, a distinguished geologist and chemist, in his fascinating *Text-book of Chemical and Physical Geology*, discusses the chemical processes which take place when meteoric waters and different kinds of aqueous solutions come in contact with rocks. His work created a new scientific basis of research in this branch of economic geology. He contended that ores were obtained by leaching from the rocks traversed by the veins, and suggested the possibility of the vein-constituents being found in the adjacent rocks.

In 1855, Forchhammer, the famous chemist of Copenhagen, found traces of lead, copper, and zinc in the roofing slates of North Wales, a discovery which was held to afford conclusive proof of the origin of ore-veins by processes of lateral secretion.

In 1873, Professor F. Sandberger, of Wurzburg, dissatisfied with the meagre results obtained from the examination of sedimentary rocks, directed his attention to a systematic chemical investigation of the rocks traversed by ore-veins in different mining centres in the Black Forest, and of the vein-stuff itself.

In clay-slate he discovered copper, zinc, lead, arsenic, antimony, tin, cobalt, and nickel; in sandstone, lead and copper; while titanic and phosphoric acids were found to be present everywhere in small quantity.

Sandberger's results showed that a close relationship existed between vein-contents and the country-rock; but he was by no means satisfied as to the origin of the heavy metals. He accordingly extended his investigation to an examination of the constituents of igneous rocks.

He crushed large samples of rock and separated the constituent minerals by solutions of different densities. Samples of the individual crystallised silicates thus isolated were subjected to careful analysis, and by this means were found all the usual elements present in metalliferous veins.

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[1] George Lasius, "Observations on the Hartz Mountains," *Ores and Minerals*, vol. ii., Hanover, 1789.

Thus in olivine he found iron, nickel, copper, and cobalt; in augite, copper, cobalt, iron, nickel, lead, tin, and zinc; and in the micas many base metals. Gold, mercury, and tellurium were not sought for.

In 1880, Sandberger announced his belief that the mineral contents of veins were derived, not from some unknown depth, but from the immediate wall-rock.

Gold-bearing veins are common in slates and sandstones of marine origin; and as sea-water, according to the announcement of Sonstadt in 1872, and of Professor Liversedge in 1893, contains, according to the latter, amounts ranging from 0·54 to 1 grain to the ton, it is held by the exponents of lateral secretion that the sea is, therefore, the source of the gold in veins traversing marine sedimentaries.

It is maintained that when sediments are formed on the floor of the sea they must necessarily entangle a certain proportion of sea-water, and that when these sediments become consolidated the gold must remain in them.

The theory of lateral secretion received a new impulse from the researches of Sandberger. It seemed competent to explain the origin of many ore-veins, and although strongly opposed by Professor Stelzner, of Freiberg, and Professor Posepny, of Przibram, it found much support in America, in a more or less modified form.

Thus Emmons,[1] discussing the manner in which he considers the Leadville ore-deposits were produced, summarises his views on ore-formation in general as follows:—

(1) Ore-deposits have been deposited from solution, rarely in open cavities, most frequently by metasomatic interchange.
(2) Solutions do not necessarily come directly upwards, but simply follow the easiest channels of approach.
(3) The material was derived from sources within limited and conceivable distance, very often the older intrusive rocks.

Emmons, while supporting the principle of lateral secretion, disclaims the narrow views of Sandberger, who limited the source of the vein-contents to the wall-rock in immediate contact with the vein.[2]

In the critical discussion which followed the publication of Professor Posepny's paper on "The Genesis of Ore Deposits," in 1893, Blake and Winslow reaffirmed their belief that the zinc- and lead-ores of Wisconsin were formed by lateral secretion.[3]

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[1] S. F. Emmons, "The Genesis of Certain Ore Deposits," *Trans. Am. Inst. M.E.*, vol. xxx. p. 125.

[2] *The Genesis of Ore Deposits*, 1901, p. 199.

[3] *Loc. cit.*, p. 188.

Becker, while strongly dissenting from Posepny's view that metasomatic replacement was incapable of producing such pronounced ore-bodies as those at Leadville, makes a clear statement of the supposed operation of metasomatic processes. He says, "Replacement, like solution, must occur along fissures or channels, and metasomatic ore-bodies will present analogies in form to the open spaces of caves of solution" (*loc. cit.*, p. 206).

Rickard discusses the problem of ore-formation from a wide standpoint, and is not a dogmatic supporter of the extreme doctrines of either ascension or lateral secretion.[1] He affirms that there is no ground for the belief in the existence of a reservoir of water at great depth, and maintains that all ascending water must at one time have been descending water.

This last can only be true in regard to meteoric waters. So far as the existence of deep-seated water is concerned, his view is not in accord with the hydro-fusion theory of modern petrologists.

Rickard, possessing a personal knowledge of the goldfields of Australia and New Zealand, discusses the probable origin of the veins of the Thames goldfield in the latter country; and in the main agrees with Captain Hutton that they were formed by processes of lateral secretion by thermal waters.

Professor J. Le Conte, in a carefully prepared thesis, combats the extreme views of both Posepny and Sandberger (*loc. cit.*, p. 270). He makes an earnest attempt to combine what is true in each, and reconcile their differences. It is manifest, however, that he leans favourably to the side of lateral secretion processes, although not defined as such.

He considers both sides partly right and both partly wrong. Ascensionists, he thinks, are right, in deriving metals mainly by ascending solutions from great depths, but wrong in imagining these depths to be an exceptionally metalliferous barysphere; and wrong in not allowing subordinate contributions by lateral currents from the wall-rock higher up.

The lateral-secretionists, on the other hand, are right, he thinks, in deriving metals by leaching from the wall-rock, but wrong in not making the thermosphere the main source.

Le Conte succinctly summarises his views in the following terms:—

(1) Ore-deposits, using the term in its widest sense, may take place from many kinds of waters, but especially from alkaline solutions; for these are the natural solvents of metallic sulphides, and metallic sulphides are usually the original form of such deposits.

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[1] *Loc. cit.*, pp. 190 and 211.

(2) They may take place from waters at any temperature and pressure, but mainly from those at high temperature and under heavy pressure, because, on account of their great solvent power, such waters are heavily freighted with metals.
(3) The depositing waters may be moving in any direction—up-coming, horizontally moving, or even sometimes down-going, but mainly up-coming, because by losing heat and pressure at every step, such waters are sure to deposit their contents abundantly.
(4) Deposits may take place in any kind of waterway—in open fissures, in incipient fissures, joints, cracks, and even in porous sandstones, but especially in great open fissures, because these are the main highways of ascending waters from the greatest depths.
(5) Deposits may be found in many regions, and in many kinds of rocks, but mainly in mountain regions, and in metamorphic and igneous rocks, because the thermosphere is nearer the surface, and ready access thereto through great fissures is found mostly in these regions and in these rocks.

Professor C. R. Van Hise, in a classic paper on "Some Principles controlling Deposition of Ores,"[1] defines his views in the following sentences:—

(1) That the greater number of ore-deposits is the result of the work of underground water.
(2) That the material for ore-deposits is derived from rocks within the zone of fracture.
(3) That by far the major part of the water depositing ores is meteoric.
(4) That the flowage of water underground is caused chiefly by gravitative stress.
(5) That the waters which perform the first work in the genesis of ore-deposits are descending waters.
(6) Lateral secretion is an essential step in the first concentration of ore-deposits. Many ores in their first concentration are precipitated by ascending waters.
(7) That sulphide ores are generally deposited by ascending waters in trunk channels. It is believed that the downward transportation of metals is the most important of the causes explaining the character of the upper portions of lodes; but whether this be so or not, their peculiar

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[1] *Loc. cit.*, p. 282; also *Trans. Amer. Inst. M.E.*, vol. xxx., 1900, p. 27.

characters are certainly due to the effect of descending waters.

(8) That the majority of ore-deposits, if not all, are partly deposited in pre-existing openings, and are partly replacements of wall-rocks.

From the above he seems to attach too little importance to the genetic connection existing between ore-deposits and eruptive processes; and places much dependence upon the formative power of meteoric waters.

Professor Kemp[1] contends that mining operations in America show conclusively that mines become drier with increasing depth; and deep mining in South Africa, Australia, and New Zealand adds confirmation to this view. The dryness of mines in depth seems to destroy the foundations of Van Hise's main contention respecting the underground circulation of meteoric water.

Van Hise admits that there are ore-deposits which have a direct igneous origin, but thinks they are of limited extent. In his rejoinder to Kemp he seems to somewhat modify his former conception with respect to the rôle of meteoric waters in vein-formation, and admits that the rôle of igneous intrusions may be very considerable.[2]

It has been suggested by the opponents of lateral secretion that the metals contained in the silicate minerals of eruptive rocks are not primary, but secondary, constituents. According to their view, lateral secretion is only a process of concentration.

Ascension of Solutions.—According to this theory, it is assumed that the material which fills a lode has been brought in solution from great depths, and not from the rocks in the immediate vicinity of the lode.

In his classic memoir on *The Genesis of Ore Deposits*, the late Professor Posepny, an ardent supporter of the ascension hypothesis, laid great stress upon the occurrence of sulphur and cinnabar at Sulphur Bank impregnating a decomposed basalt, and still mildly in process of formation from gaseous emanations and hot mineral waters.

Similar conditions exist at Steamboat Springs in Western Nevada, where we have an example of a mineral vein in process of formation. The matrix is banded siliceous vein-stone containing iron and copper sulphides, sulphur, and metallic gold.

Sandberger, who was an equally strenuous supporter of lateral secretion, objected to this view, on the ground that he knew of no

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[1] J. F. Kemp, "The Rôle of Aqueous Rocks in the Formation of Veins," *The Genesis of Ore Deposits*, 1901, p. 681.

[2] C. R. Van Hise, *The Genesis of Ore Deposits*, 1901, Discussion, p. 763.

spring which deposited mineral incrustations on the walls of their channels. He regarded the Sulphur Bank and Steamboat Springs phenomena as exceptional.

Becker, who made a special examination of the deposits at Sulphur Bank and Steamboat Springs, strongly opposed the views of the extreme ascensionists. And with regard to the origin of the deposits, he expressed the following views:—"The evidence is overwhelming that the cinnabar, pyrite, and gold of the quicksilver mines of the Pacific slope reached their present positions in hot solutions of double sulphides, which were leached out from masses underlying the granite and the granite itself."[1] Further on he says: "I regard many of the gold veins of California as having an origin entirely similar to that of the quicksilver deposits."

Becker's views postulate a new hypothesis, which lies midway between the ascension and lateral-secretion theories, and expresses our present knowledge of ore-formation more nearly than the extreme views of Posepny and Sandberger.

According to the definition of lateral secretion by the latter, the descending waters became charged with mineral matter by leaching the rocks in the region of vadose circulation. On the other hand, Posepny assumed that the ascending waters became charged at great depths by coming in contact with a deep-seated but hypothetical repository of metalliferous matter.

The modification suggested by Becker favours the ascension theory, and differs only from the lateral-secretion hypothesis in assuming a deeper source for the mineral contents of the vein-matter.

Summary.—From the data recorded in the preceding pages, we may deduce the following conclusions respecting the genesis of ore-deposits:—

(1) That the majority of ore-deposits are genetically connected with igneous intrusions which may be plutonic or volcanic.
(2) That circulating underground waters and gases are the principal agents concerned in the dissolution, primary concentration, and deposition of vein-matter.
(3) That ore-deposits do not necessarily occupy pre-existing fissures and cavities.
(4) That vein-filling was in many cases effected by metasomatic replacement.
(5) That vein-filling waters are ascending waters, but not necessarily deep-seated.

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[1] G. F. Becker, "The Geology of the Quicksilver Deposits of the Pacific Slope," *United States Geol. Survey*, Monograph xxiii., 1888, p. 449.

(6) That the mineral contents are derived from rocks contiguous to the zone of fracture or zone of metamorphism.
(7) That the accessory agents of dissolution are heat and pressure, aided by dissolved alkaline minerals.
(8) That precipitation from the ascending waters takes place in more or less orderly horizontal zones in accordance with the laws governing solution and precipitation.
(9) That secondary enrichment is, in the majority of cases, due to the migration of mineral contents from a higher to a lower level, through the agency of descending meteoric waters.

The theories of lateral secretion and ascension of solutions are based on the fundamental assumption that the mineral matter filling cavities was deposited from circulating waters. Their differences lie principally in the different conceptions as to the direction and operation of the circulating liquids.

(1) The lateral-secretion theory supposes :—
  (*a*) That the filling of cavities was the work of descending meteoric waters.
  (*b*) That the filling matter was principally obtained from the adjacent rocks by a process of leaching.

(2) The ascension theory assumes :—
  (*a*) That the filling of veins was effected by deep circulating waters, ascending through open, or partially open fissures.
  (*b*) That the mineral and metallic contents were derived from a deep-seated mineralised zone.

Many writers assume that ascending and descending waters are merely units in what may be termed a hydraulic circuit, the interchange being caused by gravitation, assisted by capillary action and the difference of temperature of the ascending and descending waters.

Much of the movement, it is claimed, is necessarily lateral, and towards channels filled with ascending waters.

It was maintained by Professor Posepny and Dr Raymond that descending waters were merely oxidising and incapable of depositing sulphides. This contention has, however, been successfully disproved by Emmons, Becker, Van Hise, and other American geologists, who have shown the existence of secondary sulphides both above and below water-level, or in what may be termed the zone of vadose circulation.

Professor Daubree always maintained that metallic sulphides could not be deposited without the agency of organic matter. But Skey, as far back as 1870, proved experimentally that "from its solution of carbonate of soda, potash, and ammonia, gold is reduced by sulphides, but not from its solutions in alkaline sulphides."[1] He found that one grain of iron pyrites was able to reduce 8·5 grains of gold.

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[1] Skey, *Trans. New Zealand Inst.*, vol. iii. p. 226, 1870.

CHAPTER VII.

ORES AND MINERALS CONSIDERED ECONOMICALLY.

EVERY mining student should possess a general knowledge of the conditions under which the commonly useful ores and minerals occur in Nature; and of the market condition, quality, and value of the minerals intended for metallurgical and manufacturing purposes.

The market values are subject to continual fluctuations, and the quotations given must be regarded more as a guide than a standard of selling-prices. The minerals and ores are dealt with in alphabetic order.

ALUM.

The principal sources of alum are alunite, alum shales, bauxite, and cryolite.

Alunite occurs in veins and masses in eruptive rocks, and for the most part in acid lavas of later date, in which it has probably been formed by metasomatic replacement attending waning solfataric action.

At Tolfa, near Civita Vecchia, in the neighbourhood of Rome, it occurs as thin, irregular veins, which are supposed to have been formed in contraction-cracks by the action of hot waters and sulphurous gases upon the felspars of the containing trachyte.

An important deposit of alunite occurs at Bullahdelah Mountain, in New South Wales. It consists of minerals ranging from pure alunite to an impure form containing 40 per cent. of silica. The deposit is over a mile long, nearly three-quarters of a mile wide, and the thickest band of stone varies from 60 to 70 yards wide. It is genetically connected with felsitic dykes, which traverse Carboniferous slates. The average composition of the mineral is as follows :—

	Per cent.
Water,	7·80
Alumina,	34·70
Iron oxide,	1·00
Potash,	6·10
Sulphuric acid,	32·30
Silica,	18·10
	100·00

Alum is obtained by calcining and washing alunite; and evaporating the liquors.

Natural alum is obtained in considerable quantities in England and Scotland from the coal-shales and alum-clays.

Bauxite is an important source of alum and aluminium sulphate (concentrated alum) in America, France, and Germany. It is an aluminium-iron hydrate—an aluminous form of limonite—containing generally from 50 to 60 per cent. of alumina (Al_2O_3).

Of American bauxite, from 65 to 70 per cent. is produced in the State of Georgia, and the balance in Arkansas and Alabama.

The bauxite deposits in the Department of Var, in France, are mostly massive oolitic, and cemented by carbonate of lime. They occur in old lake basins, extending westward from Cannet du Luc. The origin of the mineral is still doubtful; but by some writers it is supposed to have been genetically connected with solfataric action in and around the ancient lakes.

At Baux, near Arles, the bauxite occurs oolitic, and as grains in a compact limestone.

Only the varieties of bauxite free from iron oxide can be utilised in the manufacture of alum. The purer grades are used for the preparation of aluminium hydrate, from which the metal aluminium is manufactured.

Cryolite, another important source of alum, still continues to be derived from the mines at Ivigtut, in Greenland.

The alunite of New South Wales is valued at about £3 per ton.

The American domestic bauxite ranges in value from 14s. to 18s. per ton. French bauxite is delivered at American seaports at a somewhat lower rate than the domestic mineral on account of the railroad-freight charges.

ALUMINIUM.

This metal is largely manufactured in Germany, America, and France from bauxite principally produced in the Department of Var, in Southern France. (For *Bauxite*, see "Alum.")

ANTIMONY.

The only commercial ore of antimony is the sulphide, antimonite; the oxides are secondary products, found near the outcrop. The sulphide generally occurs in veins in schist, slate, and sandstone; and also associated to a small extent with ores of lead, bismuth, and copper.

The principal producers of antimonite are France, Algeria, Italy, Mexico, Turkey, Hungary, China, and Canada. Considerable deposits occur in New South Wales and New Zealand, but the ore is generally of too low a grade to be payable.

The ore must be very pure to be worth handling. When under 25 per cent. in the mine it is practically impossible to separate the ore from its gangue.

Antimony-ores are bought by smelters on a basis of 45 per cent. of metal, each unit above that being paid for at schedule rates. Under 45 per cent. there is a discount until the limit is reached, below which the ore has no commercial value. English smelters do not care to touch ores containing under 40 per cent. of metal. In America, an ore to be marketable must contain not less than 50 per cent. of antimony.

Ores intended for the English market must be free from lead, arsenic, copper, and zinc. One per cent. of lead will render the ore unsaleable.

The size of the ore also affects the market value of the dressed material, which should not be broken in pieces smaller than a hazel-nut.

An allowance is made for gold and silver when present in sufficient quantity to pay for extraction. The smelters' payments are based on the dry weight. The percentage of metal should be determined by the wet assay, the fire assay not being sufficiently reliable.

Antimony is mostly used for the manufacture of type-metal. Its value fluctuates considerably

ARSENIC.

The arsenious oxide of commerce is manufactured from arsenical pyrites, which is generally mined in association with ores of gold, copper, or tin. Mispickel is largely produced in Germany, France, Canada, and England.

ASBESTOS.

This mineral is found as veins in serpentine. Over 90 per cent. of the world's supply comes from Canada, and the balance from Russia, United States, Italy, and Cape Colony.

The largest Canadian quarries are situated in the Province of Quebec. The serpentine there is intersected with numerous veins of chrysolite, varying from a mere streak to 6 inches in width. The common width is 1 inch to 2 inches, and the veins cross and recross each other at every angle.

Asbestos is classed in three grades—Nos. 1, 2, and 3. No. 1—the longest and finest fibre, from $\frac{3}{4}$ inches upwards—is used for spinning purposes. No. 2 is inferior to No. 1, being harsh and less flexible, or discoloured and short, but unbroken from about $\frac{1}{2}$ inch upwards. It is used principally for engine-packing. No. 3 contains still shorter fibre, mixed with serpentine and iron oxides. When cleaned, it is used in the manufacture of cardboard, fire-proof paper, etc. The relative value of the three qualities is 4 : 2 : 1.

The cost of production depends on the number of tons of rock to be broken to obtain a ton of asbestos. According to Klein, few Canadian mines contain ground as rich as 50 tons of rock to the ton of asbestos; while the poorer mines yield only a ton for every 150 tons or more of rock.

Asbestic and fossil-meal are manufactured from the refuse—low-grade and short-fibre asbestos. They are used for covering steam-pipes and boilers and as fire-proof plaster.

The value of the raw material varies according to the quality, from £2, 10s. to £20.

ASPHALTUM.

Asphalt or bitumen occurs in a soft, viscous state, as a solid, or impregnating earths, sands, sandstones, and bituminous limestones of no particular age.

The chief sources of supply are Trinidad, Italy, France, Switzerland, United States, Germany, Venezuela, Russia, Spain, Turkey, and Hungary.

The Pitch Lake of Trinidad occupies an area of 99 acres, and varies from 20 feet to 30 feet deep. The removal of nearly 2,000,000 tons of asphalt has made little apparent impression on the deposit, the surface of which forms a sheet broken by pools and channels of rain-water. The lake contains no liquid asphalt. Nearly everywhere the deposit is firm enough to walk upon.

According to Malo,[1] the average composition of the crude asphalt is as follows :—

	Per cent.
Bitumen, ...	34
Water, ...	30
Clay, ...	36
	100

The greater part of the United States production is obtained from bituminous sandstones in California and Kentucky. The bituminous sandstone of California occurs in large quantities at various points between San Francisco and Los Angeles.[2] It contains from 12 to 18 per cent. of bitumen, the remainder being quartz-sand.

The asphalt deposits of Kentucky occur in nearly horizontal fine-grained sandstone belonging to the lower Carboniferous period.

Bituminous limestones are the most important source of asphalt in France, Switzerland, Cuba, and the States of Utah, Texas, and Indian Territory in the United States.

The Val de Travers mine, at Neuchâtel, in Switzerland, and the Seyssel mines, in France, yield an asphalt from bituminous limestone extensively used for paving purposes. At Seyssel there are seven beds of bituminous limestone, varying from 10 feet to 20 feet in thickness, and containing from 4 to 10 per cent. of bitumen.

The Turkish supply is mainly derived from Albania and Palestine. The deposits in the Dead Sea region have long been notable. The bitumen-springs at Nebi Musa contain from 30 to 40 per cent. of asphaltum.

The ozokerite deposits at Boryslaw, in Galicia, Austria, supply practically the world's annual output.

Barytes.

This mineral is found as irregular masses in schists and limestone. It is often associated with lead-ores.

The world's production is principally obtained from Germany, Great Britain, United States, and Belgium. One of the largest

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[1] Leon Malo, *L'Asphalte*, p. 20, Paris, 1888.

[2] F. V. Greene, "Asphalt and its Uses," *Trans. Am. Inst. M.E.*, vol. xvii. p. 355, 1888.

known deposits occurs at Silver Island, near the north end of Lake Superior.

Barytes is now largely employed in the manufacture of paints. The price of the raw material varies from 12s. to 21s. per ton.

BAUXITE. (See "Alum.")

BISMUTH.

Metallic bismuth generally occurs in veins in gneiss, schist, and clay-slate accompanying ores of silver, cobalt, lead, wolfram, zinc, and gold. It is chiefly derived from the silver and cobalt mines in Saxony and Bohemia.

The principal ores of commercial value are the sulphide, telluride, and carbonate, which are found associated with molybdenite, fluorite, pyrites, chalcopyrite, and apatite.

The world's supply of bismuth comes principally from the State mines in Saxony. Small quantities come from Colorado, New South Wales, and Queensland.

The supply is greater than the demand, and ores containing less than 5 per cent. of the metal leave no margin of profit. The price is about 6s. per pound.

BORAX.

This mineral occurs as incrustations in old lake basins in rainless regions, and mixed with clay in marshes and shallow lagoons. Colemanite, which is a calcium borate, is found in California in bedded deposits as large masses, more or less connected by stringers and bands. Near Daggett, the colemanite deposits vary from 5 feet to 30 feet in thickness.[1]

The world's supply is derived from the United States, Chili, Peru, Italy, and Turkey. The production of the United States is chiefly derived from the colemanite deposits in California.

Boric acid, which is largely used in the manufacture of borax, is obtained from the gaseous emanations of steam fumaroles in volcanic regions. The entire yield of it from Italy is derived from the fumaroles in the Provinces of Pisa and Grosseto.

CEMENT.

Chemically considered, cement is an intimate admixture of lime and clay. There are two kinds of cement in the market—namely, artificial and natural.

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[1] Marius R. Campbell, "Reconnaissance of the Borax Deposits of Death Valley and Mojave Desert," *Bulletin of the U.S. Geol. Survey*, No. 200, Washington, 1902.

Artificial cements are made in almost all civilised countries.

Natural cements are produced direct from rock containing more or less the requisite proportions of lime and clay. France, United States, and New Zealand produce considerable quantities of natural cement from argillaceous limestone deposits of great extent.

The hydraulic limestone at Grenoble, in France, from which the finest natural cement in the world is produced, occurs in a bed 15 feet thick, interbedded in a compact limestone. Its composition is as follows:—

	Per cent.		
Silica,	13·40	to	17·37
Alumina,	6·20	,,	12·38
Iron oxides,	3·50	,,	4·00
Calcium carbonate,	66·50	,,	60·75
Magnesium carbonate,	6·00	,,	traces
Water, loss, etc.,	4·40	,,	5·50
	100·00		100·00

The hydraulic limestones in New Zealand are of Upper Cretaceous age. They vary from 20 feet to 140 feet in thickness. Cement manufactured from the rock at Mahurangi showed the following composition:—

	Per cent.
Silica,	25·44
Alumina, Iron oxides,	15·76
Lime carbonate,	55·06
Magnesia carbonate,	2·05
Alkalies and loss,	1·69
	100·00

The iron seldom exceeds 3 per cent. It mostly occurs as grains of glauconite.

Natural cements are often equal to the best artificial Portland cements, but, generally speaking, they lack the uniformity in composition of the artificial product.

CHROMIUM.

Chromite of iron occurs in irregular masses in peridotite and serpentine. The world's supply is principally produced by Turkey, New Caledonia, Greece, New South Wales, Canada, and

United States. At present Turkey furnishes about 60 per cent. and New Caledonia 26 per cent. of the total output.

Chromite is used in the manufacture of steel, and in the production of chromates of the alkalies, which are extensively used as pigments and for tanning purposes.

For the manufacture of chrome-steel the ore should contain not less than 50 per cent. of the sesquioxide, and must be free from copper.

The price varies from £2 to £3, 12s., according to the percentage of the sesquioxide.

COAL.

The mode of occurrence, origin, and distribution of coal have already been discussed in Chapter II. The chief coal-producing countries are as follows :—

	Tons.
United States annual production exceeds .	350,000,000
United Kingdom ,, ,, ,, .	250,000,000
Germany ,, ,, ,, .	170,000,000
France ,, ,, ,, .	30,000,000
Belgium ,, ,, ,, .	20,000,000
Russia ,, ,, ,, .	20,000,000
Japan ,, ,, ,, .	10,000,000

The world's yearly production of coal is about 1,000,000,000 tons and the value exceeds that of all other mineral productions, including gold, silver, copper, iron, tin, diamonds, etc., more than twofold.

Of the American output in 1904, the chief producing States were as follows :—

	Short tons.
Pennsylvania, . . .	98,000,000
Illinois, ...	37,000,000
West Virginia, . . .	30,500,000
Ohio, ...	25,000,000
Alabama, ...	12,250,000

The great bulk of the coal won in Germany is obtained in the great coal regions of Westphalia.

COBALT.

This metal has not been found in the metallic state. It commonly occurs combined with arsenic and sulphur. The principal ores are smaltite, the arsenide of cobalt; and cobaltine, the sulphide and arsenide. The earthy oxide is a considerable source of cobalt. It is a gossan product, and essentially a hydrous oxide of manganese mixed with a variable percentage of cobalt.

The ores of cobalt are generally found accompanying those of nickel and silver, and sometimes those of copper and manganese.

The cobaltiferous bands at Skutterud, in Norway, consist of alternating thin beds of mica-schist and quartz-schist, the latter impregnated with pyrites, cobalt glance, cobaltiferous mispickel, and a little chalcopyrite. So far they have not proved of much value.

The hydrated oxide of cobalt of New Caledonia is largely exported to Europe and America. It occurs intimately associated with hydrated oxide of manganese, which is found in irregular *pockets* of red clay in serpentine. This cobaltiferous wad contains from 2½ to 5 per cent. of cobalt, and at present is the principal source of the world's supply.

Up till the end of 1901 a considerable portion of the domestic supply of the United States was obtained as a by-product in the treatment of the lead-ores from Mine La Motte, in the State of Missouri.

COPPER.

The chief sources of copper are the sulphides—principally the yellow sulphide—and native copper. When the ore occurs in large masses capable of being cheaply mined, 1 to 3 per cent. of the metal is payable. The great bulk of the copper annually placed in the market is produced from very low-grade ores, associated with iron pyrites, and often containing a little gold and silver.

The most important copper-mines of the world at the present time are those of Mansfeld, in Germany; Rio Tinto and Tharsis, in Spain; San Domingo, in Portugal; Lake Superior, Montana, and Arizona, in the United States; and Mount Lyell, in Tasmania.

The world's production of copper amounts to over 580,000 tons, of which the United States produces over 55 per cent.

UNITED STATES.—At Lake Superior, in Michigan, the copper is found in beds of conglomerate and sandstone, interstratified with flows of amygdaloidal diabase, forming what is known as the Keweenawan series, and which is probably of pre-Cambrian age. The conglomerates are the most productive. In them the copper occurs as the cementing material; it has evidently been deposited from an aqueous solution. The diabase flows are amygdaloidal in their upper layers, and occasionally the lower side also may be vesicular.[1] They contain rich patches of native copper associated with native silver.

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[1] T. A. Rickard, *The Copper Mines of Lake Superior*, p. 25, 1905, New York.

Copper is also found in fissure-veins crossing the Keweenawan series of the northern end of the peninsula. The veins vary from 10 feet to 30 feet in width. They are richest in the diabase, in which the copper occurs in the native state, being generally found in masses, the largest mass weighing nearly 600 tons.

The most productive mines in this region are the "Calumet and Hecla," "Osceola," "Tamarack," and "Quincy." The two former have shafts reaching the great depth of nearly 5000 feet.

It should be noted that extremely low-grade ore, containing as little as 1·5 per cent of copper, are made to yield large profits in the Lake Superior district. To achieve this result enormous quantities of ore are mined and stamped.

The distinguishing features of the Michigan copper-mines are the enormous tonnage of low-grade ore stamped, the low cost of production, and the great depth of the mines.

The production of the copper-mines in Butte district, in Montana, is even greater than that of the Lake Superior mines. The most productive mines are the Anaconda, Parrot, Butte and Boston, Boston and Montana, and Colorado.

The copper is found in east and west lodes in granite. The main lode, which runs through the Anaconda and Parrot mines, has proved productive for a distance of 3 miles along the strike.

The average width of the lodes is 10 feet. The copper occurs principally as sulphides, which are silver-bearing, the proportion of silver varying from ½ oz. to 2 oz. per unit of copper.

The Arizona copper-mines produce large quantities of oxides and carbonates, which occur in or near a Carboniferous limestone, often near the point of contact with granite, or with sandstones.

SPAIN AND PORTUGAL.—The copper-deposits at Rio Tinto, Tharsis, and San Domingo are of great extent. They consist of compact pyrites containing from 1 to 2½ per cent. of copper-pyrites disseminated throughout the whole mass.

Next to the Calumet and Hecla, the Rio Tinto is the greatest copper-mine in the globe.

GERMANY.—The Mansfeld copper-mines in Saxony have been worked since the twelfth century. The ore is found in a flat-lying bed of cupriferous shale of Upper Permian age, and, notwithstanding its thinness and comparatively low grade in metal, it can be worked with profit. It occurs in finely disseminated particles throughout the shale. A golden-yellow colour indicates chalcopyrites; a bluish and reddish variegated colour indicates bornite; a steel-gray, copper-glance; a grayish-yellow, iron-pyrites; and a leaden-gray, galena.

The whole bed contains copper, but only the bottom 3 inch or

4 inch are rich, and on an average contain 2 to 3 per cent. of copper and 163 oz. of silver to the ton of copper.

AUSTRALASIA.—Mount Lyell Mine, on the west coast of Tasmania, is one of the principal copper-producers in the Commonwealth of Australia.

At the surface the lode was a huge gossan, consisting of dense dark hæmatite and friable limonite containing gold and silver. Below the oxidised zone the ore passed into massive pyrites lying between talcose schists on one side and conglomerates on the other.

In New South Wales there is a copper-bearing area variously estimated at from 5000 to 6500 square miles. It is situated in the great arid plain lying between the Darling, Bogan, and Lachlan rivers. The country-rock is Silurian slate, which is traversed by fissure-veins. None of the mines have been worked continuously.

CRYOLITE.

This is a fluoride of sodium and aluminium, containing about 51 per cent. of sodium fluoride when pure. Practically the whole of the world's supply is obtained from the Danish cryolite-mines at Ivigtut, on the west coast of Greenland.

The white cryolite occurs in great snow-white masses, which are partially transparent. It constitutes a large bed or mass in a granitic dyke which traverses a gray gneiss.

Associated with the cryolite are quartz, siderite, galena, pyrites, chalcopyrite, wolframite; also fluorite, mispickel, and cassiterite. The ore is confined to the granite, but there is no clear line of demarcation between it and the surrounding rock into which it passes. The mineral is mined by open cuts about 200 feet wide and 100 feet or more deep.[1]

The Greenland mines produce nearly 8000 tons of cryolite a year, valued at about £3 per ton at the mines. The bulk of the output is exported to the United States for the manufacture of aluminium, for making sodium and aluminium salts, and for the manufacture of sodium fluoride, which is used to prevent incrustations forming in steam-boilers.

Cryolite is also used to a limited extent in the manufacture of an opalescent glass which resembles French porcelain.

DIAMOND.

Until the discovery of the mines at Jagersfontein and Kimberley, in the years 1870 and 1871, there is no record that diamonds had been found except in alluvial deposits or conglomerates.

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[1] *Mineral Resources of United States*, 1901, Washington, p. 883.

Kimberley Diamond Mines.—The diamonds on this field occur in a breccia filling the pipes or craters of what are believed to be old volcanoes. The breccia is mainly composed of serpentinised peridotite with fragments of black shale, granite, and diorite which do not commonly exceed an inch in diameter.[1]

There are five necks in close proximity, that is, within a radius of a few miles. They occur on a gently undulating plateau at an elevation of about 4000 feet above the sea; and do not project above the level of the surrounding country in the manner so characteristic of breccias or agglomerates which have consolidated in the pipes of old volcanoes.

The smallest pipe, known as the De Beers Mine, has a surface area of 22 acres; and the largest, an area of 45 acres.

The succession of rocks which the pipe penetrates in the Kimberley Mine is as follows[2]:—

	Feet.
Surface soil and debris,	30
Basalt,	51
Shale,	250
Conglomerate (glacial?),	10
Melaphyre (olivine diabase),	394
Quartzite,	401
Shale,	260
Quartz-porphyry,	1072
Shale (ascertained thickness),	89
Total,	1557

The bedding-planes of the various strata are horizontal, but it is noteworthy that the edges of the shales at the sides of the pipes are bent upwards at an angle of about 40° for a distance of about 3 feet back. The faces of the harder rocks, the melaphyre and quartzites, are not bent, but polished and striated in various directions, mostly at an angle of 45° to the vertical. Heneage[3] says that some of the scratches have apparently been made by descending bodies. The wall-rocks show no signs of fusion.

From the surface down nearly to the bottom of the melaphyre-bed, for a depth varying from 45 feet to 60 feet, the material filling the vent was oxidised into a soft, yellowish-coloured clay. At a depth of 100 feet it became darker and harder, acquiring a slate-

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[1] Professor T. G. Bonney, F.R.S., *Proceedings of the Royal Society*, vol. lxv. p. 223, 1899.

[2] Gardner F. Williams, "The Genesis of the Diamond," *Trans. Am. Inst. M.E.*, Pamphlet, Sept. 1904.

[3] E. F. Heneage, "The Phenomena of the Diamondiferous Deposits of South Africa," *Trans. Inst. Min. and Met.*, vol. xii. p. 115, 1902-3.

blue or dark-green colour in places, resembling some varieties of serpentine.

Four-fifths of the material forming the *blue ground* is a dark-green dense serpentine, which contains glistening plates of brown mica, small dark-red garnets (mostly pyrope), large dark-green crystals and grains of olivine, besides enstatite, smaragdite, chrome-diopside, chromite, magnetite, and ilmenite. Small fragments of altered black shale are often so abundant as to give the rock a brecciated appearance.

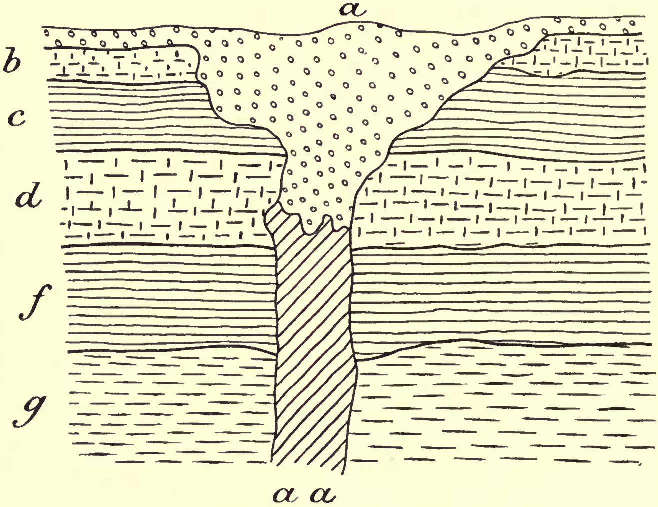

FIG. 67.—Section of Kimberley Diamond Pipe.

a, Yellow ground. *aa*, Blue ground. *b*, Basalt sheet. *c*, Shales. *d*, Melaphyre. *f*, Quartzite. *g*, Slates.

The *blue ground* is greasy to the touch. When exposed to the weather for a time it soon disintegrates, and is then easily crushed, the diamonds being afterwards extracted by washing and hand-picking.

The late Professor H. C. Lewis[1] described the blue ground as a porphyritic volcanic peridotite of basaltic structure for which he proposed the name "Kimberlite."

It has been noted by several writers that while the composition of the material filling the pipes appears to be the same in all, each mine has its own particular kind of diamond which is so distinctive

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[1] Professor H. C. Lewis, "The Matrix of the Diamond," Manchester Meeting, British Association, Aug. and Sept. 1887.

that an expert buyer can usually say from which mine any particular stone is derived.

A certain proportion of the diamonds are broken crystals, and seldom, or perhaps never, have the corresponding pieces been found.

Many of the diamonds are in a state of stress, and some fly to pieces or splinter when removed from their matrix and when being cut.

Professor Bonney[1] believes that the diamond is a primary constituent of the igneous rock as much as the garnet, mica, and other minerals with which it is associated. He believes that the diamond was formed neither by the action of molten rock on carbonaceous matter nor by the action of steam or hot water in a subsequent solfataric stage of the volcano, but was segregrated by the usual processes of differentiation, in some deep-seated magma which was afterwards forced up from below into the pipes.

Gardner F. Williams[2] agrees with Professor Bonney that the blue ground must be designated a breccia which has been forced up from below by some igneous agency, possibly in the nature of a mud volcano. Among the facts which led him to this belief he mentions the frequent occurrence of broken diamonds embedded in the hard Kimberlite, as well as pebbles and boulders with polished surfaces as if water-worn.

Professor Lewis advanced the theory that the diamonds were formed from hydrocarbons derived from the fragments of carbonaceous shale enclosed in the blue ground, which he regarded as a true lava. This view is contested by Mr Williams, who states that all the pipes containing Kimberlite do not contain diamonds, while diamonds exist in some mines, such as those in the Pretoria district, where no carbonaceous shales are to be found.

Parent Rock of Diamond.—Mr Williams, while agreeing with Professor Bonney that the diamonds are a primary constituent of some deep-seated igneous rock, denies that eclogite is the parent rock of the gems at Kimberley.

Professor Bonney,[3] in 1899, reported the discovery of diamonds in specimens of a coarsely crystalline garnetiferous rock, related to eclogite, obtained from the Newlands mines, situated about 40 miles from Kimberley. Commenting on this discovery, he

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[1] Professor T. G. Bonney, *Proceedings of the Royal Society*, vol. lxv. p. 223, 1899.

[2] Gardner F. Williams, "The Genesis of the Diamond," *Trans. Am. Inst. M.E.*, Pamphlet, Sept. 1904.

[3] Professor Bonney, *Proceedings of the Royal Society*, vol. lxv. p. 225, 1899.

concluded that eclogite was the parent-rock of the diamond in South Africa, a view which has generally been accepted by English geologists since that date.

The statement that eclogite was the original matrix of the diamond caused Mr Williams, for many years General Manager of the Kimberley mines, to carefully examine the eclogite which occurs in tons in all the pipes, where it is treated as waste rock. Twenty tons of this rock were collected and tested by crushing and jigging in a test-plant, but not a single diamond was found in the material. Mr Williams further states that he had also examined hundreds of pieces of eclogite, but never found a diamond, nor had he ever heard of a diamond having been found in this rock during all the years the mines had been worked.

The occurrence of diamonds in the eclogite from Newlands Mine must be regarded as sporadic and not general. That a peridotite or some ultra-basic igneous rock was the parent-rock of South African diamonds may be inferred from the laws of magmatic paragenesis.

Genesis of Diamond.—Assuming the diamond to be a primary constituent of an igneous rock, the original condition of the carbon is still a matter for conjecture. Did the gem crystallise from carbonaceous matter, from a hydrocarbon, carbon dioxide, or a carbide? Of the source of the carbon nothing definite is known, or of the processes which prevented its oxidation along with the iron with which it is always associated. It is important to remember that the diamond-bearing pipes in the Transvaal penetrate carbonaceous shales.

Williams mentions that large diamonds have been found enclosing small ones, while twins are not rare, from which it may be inferred that the formation or growth of the diamond followed the ordinary laws of crystallisation in a magmatic solution of rock-material.

Moissan, in his diamond-making experiments, fused iron rich in carbon, and allowed it to cool in such a way that the separation of the excess of carbon took place under pressure. In this way microscopic diamonds were formed. Microscopic diamonds have been found in ordinary cast-iron; hence it is inferred that abnormal pressure is not necessary to ensure success in the experiment.

The experiments of Dr Friedlander have a closer bearing upon the natural formation of diamonds. Friedlander[1] fused a small piece of olivine, a centimetre in diameter, by means of a gas blow-

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[1] E. F. Heneage, "The Phenomena of the Diamondiferous Deposits in South Africa," *Trans. Inst. Min. and Met.*, vol. xii. p. 125.

pipe, kept the upper portion in the molten state for some time by playing upon it with the flame, and stirred it with a little rod of graphite. After solidification the silicate was found to contain a vast number of microscopic crystals, but only in the part which had been in contact with the carbon. The crystals are octahedral or tetrahedral in form, are unattacked by hydrofluoric and sulphuric acids, have a high refractive index, sink slowly in methylene-iodide, burn away when heated in a current of oxygen, and are unaltered if heated in a current of carbonic acid. The stony matter containing them scratches corundum. Hence Friedlander infers that they are diamonds, and that the South African diamonds may have been actually formed, as already suggested, by the action of a molten silicate, such as olivine, on graphite. Carbonaceous shales are intruded by the diamond-bearing rock, and numerous fragments of the Triassic Karoo shale, much altered, are found enclosed in the blue ground itself.

Diamond in Dolerite.—The discovery of a diamond in the original matrix was reported in July 1904, at Oakey Creek, in New South Wales, and has since been confirmed by the Government geologist.

The rock in which the diamond was found is a dolerite, therefore entirely distinct from the volcanic breccia in the Kimberley pipes. The diamond is firmly embedded to the extent of about two-thirds of its bulk in the rock. It is an irregularly shaped white crystal, weighing perhaps one-third of a carat.

The discovery is interesting, inasmuch as it presents features which are altogether new as far as the occurrence of diamonds is concerned, and a careful investigation of the surrounding geologic conditions may throw much valuable light on the genesis of the diamond.

Diamond Placers.—Diamonds are found in loose alluvial deposits and conglomerates in India, Brazil, Vaal River, New South Wales, Borneo and British Guiana.

The Deccan mines in India are of great antiquity, and celebrated more for the size and purity of the gems than the quantity produced. The diamonds are found in a layer of broken sandstone, quartz, jasper, flint, and granite interspersed with masses of calcareous conglomerate.[1] The layer is about 20 feet thick and covered with a few feet of black "cotton soil."

The diamond placers in the province of Minas Geraes, in Brazil, consist of clay, quartz, pebbles, and sand charged with iron oxide,[2] in many places covered by 30 feet or more of alluvial detritus. These deposits have been traced along the rivers and

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[1] Tavernier, *Voyages en Turquie, en Perse et aux Indes*, Paris, 1676–79.

[2] "The Diamond Fields of Brazil," *Report of U.S. Minister Bryan*, 1899.

ravines to the conglomerate beds which provided the material contained in them. The conglomerates are chiefly composed of a micaceous sandstone which is manifestly not the original matrix of the diamonds. The gems were probably derived from some rock-surface subjected to denudation at the time the sandstone was being formed.

The greatest diamonds of which there is any record prior to 1905 are the Koh-i-nor, 793 carats, the Great Mogul, 787·5 carats, and the Regent, 410 carats, all found in the great mines of Gani-Coulour and Gani-Parteal, in India. A stone of over 400 carats was found at Kimberley in 1884, and one of 972 carats, named the "Excelsior," at Jagersfontein. The great Cullinan diamond found early in 1905 in the Premier Mine, 31 miles from Pretoria, is reported to weigh 3024·75 carats, its size being 2½ inches by 2 inches by 4 inches. This is the largest stone in the world. It is said to be perfect in colour and free from flaws.

The great bulk of the world's supply of diamonds at present comes from the Kimberley mines, which in 1903 are reported to have produced stones to the value of nearly four millions sterling.

FIRECLAY.

This material occurs in stratified layers or beds generally in association with seams of coal. As a rule it lies under the coal, and is the soil on which the coal vegetation grew.

Fireclays are found in all coal-bearing regions, but all coal-seams are not underlain by material suitable for use as a fireclay. Good fireclays should contain from 52 to 62 per cent. of silica, 22 to 32 per cent. of alumina, and 10 to 14 per cent. of water. The presence of 1 per cent. of lime, magnesia, potash, or soda renders a clay too fusible to be useful for fireclay purposes. Iron oxides are also injurious, and when over 3 per cent. of the protoxide is present the clay should be discarded. Stourbridge fireclay contains about 2 per cent.

China-clay or kaolin is found in veins and irregular deposits in places where granite has been altered probably by the emanation of steam and gases from cracks and fissures.

Investigation has shown that the kaolinisation of granite and other highly acidic rocks is not the result of mere atmospheric weathering. That decomposition of the felspars in the zone of katamorphism does take place is well known, but the deep-seated kaolinisation which has been noted in Cornwall, Devon, New South Wales, Queensland, and New Zealand must be ascribed to fumarolic agencies.

FLUORITE.

This mineral, often called "fluorspar," is generally found in veins in limestone, gneiss, sandstones, and clay-slate. It also occurs as the gangue of metallic ores, especially of lead.

Fluorite is chiefly used as a flux for iron-ores. A small quantity is employed in the manufacture of opalescent glass, and for the production of hydrofluoric acid.

The world's output amounts to over 60,000 tons a year, of which the United States produces about one-third and Prussia about one-quarter. The value varies from 16s. to £1, 2s. per ton.

GOLD.

This metal is found in veins in nearly all kinds of rock, without regard to age, composition, or situation. The most productive veins are those traversing Palæozoic sedimentaries, ancient granites, and older Tertiary eruptives, especially those of a semi-basic type.

The denudation of gold-bearing rocks has liberated large quantities of gold, which have become more or less concentrated in alluvial gravels or placers. These placers are found of all ages, extending from Middle Tertiary to recent times.

The gold found in veins traversing rocks of Palæozoic or older Secondary age is generally of high value, while that derived from veins in andesite and other older Tertiary eruptives is commonly of low value, being largely alloyed with silver.

The gold of Australia, mainly or entirely derived from rocks of Palæozoic age, is of high value; as also is that of the Transvaal. The gold found in the Palæozoic mica-schists and slates in the South Island of New Zealand is almost pure; while that derived from the Tertiary andesites in Auckland is of low value, being alloyed with one-third in weight of silver.

The same feature characterises the gold produced in the Northern Hemisphere. Russian gold is of high value, while that derived from the andesites of Transylvania is of low value.

The vein and placer gold of California is commonly very pure; but that of Nevada and Colorado, mostly derived from veins traversing later eruptives, is of low grade, being generally alloyed with a large proportion of silver.

This peculiar phenomenon is too general to be accidental. It is a happening of which no adequate explanation can at present be offered.

A considerable quantity of gold is derived from silver, copper, and lead ores; and a smaller amount from ores of antimony, arsenic, manganese, and tungsten.

The value of the world's production of gold for 1904 was estimated at £75,000,000.

The gold produced by the five great producing regions in 1904 and 1905, according to Mr F. Hobart, was as follows:—

	1904.	1905.
Transvaal, . . .	£15,624,548	£20,259,192
United States, .	16,144,640	17,267,540
Australasia, . .	17,420,170	17,104,425
Russia, . . .	5,015,071	4,800,000
Canada, . . .	3,280,000	2,883,625

The most productive goldfield centres in the globe are the Rand, Kalgoorlie, and Cripple Creek.

In the Commonwealth of Australia and United States, which are of continental dimensions, the gold-bearing deposits occur under many varying geological conditions.

VICTORIA.—In this State the gold is derived from three principal sources—namely, from quartz-veins, from Tertiary deep-leads, and from recent gravel drifts.

The deep-leads consist of placer gravels of Miocene and Pliocene age. The latter have proved the most productive, and are in many places, as, for example, near Ballarat, protected by a thick sheet of basalt, the lava having flowed down the ancient valley and covered up the river gravels and sands.

The quartz-veins occur mainly in Silurian slates. The gold-bearing veins at Bendigo belong to the interesting class of ore-deposits termed *saddle-reefs*, which occur in the crown of anticlinal arches, and send down tapering prolongations or legs, running more or less parallel with bedding-planes of the country-rock.

The distinctive feature of the veins in the Ballarat Goldfield is the presence of the famous *indicator* beds. These are thin beds of black carbonaceous pyritic slate, which occur in the Silurian slates, and consequently constitute a distinct member or horizon of the country-rock. The slates stand in a nearly vertical position, while the contained gold-bearing veins lie nearly horizontal. Along the plane of intersection of the quartz-veins and *indicators* there generally occurs rich ore.

WESTERN AUSTRALIA.—In this State the crystalline schists which form the basement rocks of the country are traversed by wide belts of ancient eruptives. These eruptives are dioritic or hornblendic in different places, and are often so much altered that their original character is not always easily determined. At Kalgoorlie the hornblendic belts have been altered and silicified, probably by solfataric action, and generally exhibit a schistose structure. These mineralised belts form the gold-bearing ore-bodies.

In other parts of Western Australia the schists are traversed by wide belts of diorite and diabase, nearly always much altered, and often schistose in structure. These greenstone-schists, as they are locally termed, contain gold-bearing bodies of quartz; or they are traversed by dykes of granite, which are intersected by gold-bearing veins.

New South Wales.—In this old colony payable gold occurs in veins intersecting slates and sandstone of Silurian and Carboniferous age. According to Pittman, bedded veins are of common occurrence; and *saddle-reefs* have been worked at the Hargraves Goldfield, between Hill End and Mudgee. In the Lucknow district the gold-bearing ore occurs in irregular veins in augite-andesite near the contact of a serpentine belt.

The conglomerates forming the lowest beds of the coal-measures are gold-bearing, but not apparently in payable quantity.

In the Timbarra field the gold occurs in veins in granite, and also in pyrites disseminated throughout the granite itself. G. W. Card[1] has reported the occurrence of gold in unaltered granite and eurite.

Many of the deep-leads in this State are covered by flows of basalt.

Queensland.—The gold obtained in Queensland is derived from shallow alluvial placers and from quartz-veins. Slates and sandstones of Devonian age are gold-bearing in many parts of the State, particularly where the strata have been intruded by dykes of diorite, diabase, or porphyrite.

Many of the most productive veins at Charters Towers are enclosed in granite, but some occur in porphyry.

At Gympie Goldfield the gold occurs in veins traversing a belt of diorite.

The celebrated gold-deposit at Mount Morgan is a siliceous hæmatite, apparently the gossan of a huge pyritic contact occurring near the boundary of altered sedimentaries of Permo-carboniferous age and a dyke of hornblendic granite. The strata are also intruded by later dykes of porphyritic dolerite. The eruption of these dykes is believed to have originated the solfataric action to which the alteration of the upper part of the pyritic body is ascribed.

Tasmania.—In this small State gold is found in recent placers and in quartz-veins. The latter generally traverse strata of

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[1] G. W. Card, "On Some Rock Specimens from Auriferous Granite at Timbarra," *Records, Geol. Survey of N.S. W.*, p. 154, 1895.

Silurian age. In the Lisle and Golconda Goldfields gold occurs in veins intersecting a belt of granite.

New Zealand.—In this colony gold is found in recent and Tertiary placers, and in quartz-veins. In Otago the gold-bearing veins occur in Silurian mica-schist; in Reefton district, in claystones and sandstones of supposed Carboniferous age; and in the Hauraki Peninsula, in altered andesites of Middle Tertiary age.

The quartz conglomerates and cements at the base of the Middle Tertiary coal-measures contain water-worn gold, but seldom in payable quantities. It is noteworthy, however, that many of the richest placers in Otago and Westland are a rewash of these ancient gravels.

United States.—The gold of this country is obtained from veins, or from placers resulting from the erosion of gold-bearing country and the concentration of the valuable contents.

In the State of California, the vein-system known as the "Mother Lode" is contained in slates and altered igneous rocks of Carboniferous and Jurassic age. In Tuolumne and Calaveras counties, and more particularly at Nevada City and Grass Valley,[1] the veins occur in and near intrusive masses of granodiorite. The placers along this gold belt are among the richest in North America. The age of this remarkable stretch of gold-bearing veins is believed to be Cretaceous. The contained gold is of high quality.

A second gold belt of great importance lies in Eastern California, within the watershed of the Colorado River. In this belt the veins occur in andesites, phonolites, and trachyte of probably Middle Tertiary age. The gold is alloyed with silver, and associated with silver-ores, pyrites, etc.

The larger part of the gold-production of California is obtained from the Cretaceous belt.

The gold produced in the State of Colorado is mainly derived from veins traversing Archæan granite, or the overlying andesitic tuffs and breccias, which are typically developed in the Cripple Creek district. These igneous rocks, which consist of heavy flows as well as fragmentary matter, are believed by American geologists to be of post-Miocene age.

A considerable quantity of gold is also derived as a by-product from the silver-lead ores of Leadville and other mining centres, which occur in veins in altered sedimentaries and eruptives of Mesozoic age. Colorado is the largest gold-producing State in America. The placer-deposits are not of great extent.

The bulk of the gold of Montana is derived from lead-silver

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[1] Waldemar Lindgren, "The Geological Features of the Gold Production of North America," *Trans. Am. Inst. Min. Eng.*, vol. xxxiii. p. 817, 1903.

veins in Archæan rocks, or from veins of copper-ore occurring in intrusive granites of supposed Upper Cretaceous or Lower Tertiary age, principally developed near Butte.

In the State of Nevada, the basement rocks are sedimentaries of Palæozoic and Mesozoic age, intruded by many dykes of porphyry, and smothered by Tertiary rhyolites, andesites, and basalts. The Comstock Lode, long celebrated for its dry gold-silver ores, is contained in andesite. The silver-lead ores of Eureka[1] occur in limestones near eruptives, and carry one-third of their value in gold. The gold-silver mine De Lamar, in Southern Nevada, occurs in Palæozoic quartzites.

The gold-bearing deposits of Black Hills, in South Dakota, belong to two groups. In one group, the most important, there are the massive lodes of the Homestake district, which consist of a belt of Archæan schists, closely intersected in great areas by thin strings and veins of quartz carrying free gold and gold-bearing pyrites. This deposit, locally known as *The Belt*, is 6000 feet long and 2000 feet wide.[2] The ore is very low grade, and is only rendered profitable by the magnitude of the operations.

The gold output of British Columbia is derived from placers and veins intersecting older Mesozoic and Palæozoic rocks. In the Kootenay district the gold occurs principally in copper-bearing veins, which intersect rocks of Lower Mesozoic age.

ALASKA.—The gold of the celebrated Treadwell Mines, on Douglas Island, in Alaska, is derived from a mineralised albite-diorite, which, according to Professor Becker, has been altered and silicified by solfataric or hydrothermal action. The diorite occurs as intrusive dykes in black slates, the bedding-planes of which they closely follow.

A. C. Spencer[3] states that the ore-bearing dykes belong to a series of intrusions which appear interruptedly along the strike for a distance of about 3 miles, in a zone approximately 3000 feet wide. In the greater part of the intruded area exposures are few, and only small dykes outcrop on the side toward the centre of the island. On this side the zone seems to be irregularly limited, but next to the shore of Gatineau channel the border is defined by a heavy bed of greenstone running parallel with the slates and the intrusive dykes, and dipping with them toward the adjacent channel. The mineralised dykes which constitute the known minable ore occur just beneath this greenstone, which

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[1] Lindgren, *Geological Features*, etc., p. 829.

[2] F. B. Carpenter, "The Ore Deposits of the Black Hills of Dakota," *Trans. Am. Inst. Min. Eng.*, vol. xvii. p. 570, 1889.

[3] A. C. Spencer, "Geology of the Treadwell Ore Deposits, Alaska," Pamphlet, *Am. Inst. M.E.*, p. 14, 1904.

thus constitutes the hanging-wall both of the intrusion zone and of the ore-bodies. Many of the dykes of albite-diorite away from the hanging-wall have been greatly altered and impregnated with pyrite, but workable ore-bodies have not yet been discovered in them.

The relations of the mineralised diorite dykes to the associated country-rock are shown in the accompanying diagram.

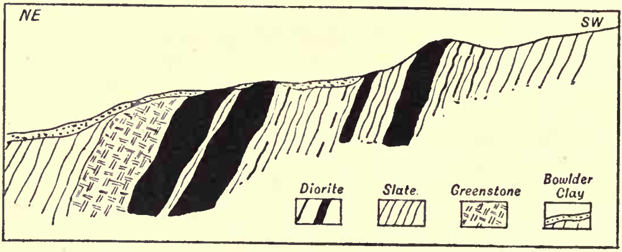

Fig. 68.—Cross-section through Alaska-Treadwell Mine and Northern Side of Douglas Island. (After Spencer.)

The gold is generally associated with pyrites in strings of quartz and calcite ramifying through the ore-body.[1]

The ore is extremely low grade, but, notwithstanding this, the annual profits are large and regular.

In the Yukon and Nome districts the gold is derived from placers.

Transvaal.—Practically the whole of the gold of this State is derived from beds of pyritic quartzose conglomerate, interbedded with quartzites of Lower Palæozoic age. The *banket* reefs, as these gold-bearing conglomerates are locally termed, vary from a few inches to 4 feet in thickness. They dip south at angles which are steeper at the outcrop than elsewhere. The most productive beds occur in a belt of quartzite about 115 feet thick.

The gold is not contained in the quartz pebbles, but in the siliceous cementing matrix. The bankets are remarkable for their great extent and uniform value over wide stretches. A detailed description of the chief banket-beds is given in Chapter II.

Russia.—Almost all the gold produced in Russia is derived from placer-deposits on the western flanks of the Ural Mountains. The foothills on the western slopes of the range consist of younger Palæozoic sedimentaries intruded by masses of granite, diorite, and diabase. Gold-bearing veins, but not generally very pro-

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[1] R. A. Kinzie, "The Treadwell Group of Mines, Douglas Island, Alaska," Pamphlet, p. 9, *Trans. Am. Inst. Min. Eng.*, vol. xxxiv. p. 334, 1894.

ductive, occur in these rocks. The returns from placer-deposits in Siberia have shown a large increase during recent years.

INDIA.—The chief gold-bearing deposits of Southern India occur in a belt of hornblendic and chloritic and argillaceous schists which are intruded by massive dykes of diabase. In the Kolar Goldfield, in the Province of Mysore, the country-rock is principally a coarse-grained gneiss, traversed by a belt of diabase, in which the gold-bearing veins occur.

BORNEO.—The gold-bearing rocks of Upper Sarawak and the mode of occurrence of the ore-bodies are of a somewhat unusual character. The rocks are a basal jurassic limestone containing, according to Professor J. Boehm, many finely preserved *Ammonites* of zonal value. The limestone is overlain by shales and sandstones which complete the series. These rocks are intruded by dykes and sills of several varieties of quartz-porphyry.[1]

Gold occurs in both the limestone and in the shales, the richest ore-bodies being found in the former. In the limestone the ore occurs in irregular caverns, fissures, and joint planes, often associated with stibnite, pyrites, blende, galena, etc. In the shales the gold is found as impregnations or disseminated.

GRAPHITE.

This mineral is commonly found in crystalline limestones, gneiss, mica-schist, and granite. It occurs in irregular masses, in beds, and often disseminated throughout the rock in thin flakes.

The world's supply is mainly derived from Austria, Ceylon, and Italy.

The finer grades of graphite are put into the market under the name *crystalline*, and the inferior grades as *amorphous*. The value of the raw product varies from £4 to £15 per ton, according to its quality.

Artificial graphite, manufactured in electric furnaces at Niagara Falls, is now produced in considerable quantities.

Graphite is used in the manufacture of crucibles, stove-polish, foundry facings, paint, lubricants, pencils, glazing, steam-packing, etc.

GYPSUM.

This mineral is commonly found in clays, marls, and shales of Secondary and Lower Tertiary age. It generally occurs in beds, not forming continuous layers, but rather layers of nodular masses.

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[1] J. S. Geikie, "The Occurrence of Gold in Upper Sarawak," *Inst. Min. and Met.*, Pamphlet, Nov. 1905.

At the present time France produces more than half the world's output. Then follow the United States, with an output amounting to 30 per cent., Canada with 8 per cent., and Great Britain with 7 per cent. of the total production.[1]

Gypsum is used in the manufacture of plaster of Paris, of plaster for interior walls of houses, and for agricultural purposes. The price varies, according to locality, from 6s. to 12s. per ton.

IRON.

The ores of iron of commercial value are siderite, limonite, or brown hæmatite, magnetite, and hæmatite or specular iron.

The carbonate or spathic ores commonly occur in beds forming members of a stratified series, or in layers of nodular masses, more especially in association with coal-measures. Clay ironstone, an impure argillaceous carbonate of iron, is common in most of the British coalfields, and in those of Pennsylvania and Ohio, in the United States. In Scotland it contains a large proportion of carbonaceous matter, and is known as *black-band* ore.

The close association of coal and iron-ore enabled Britain for many years to occupy a dominant position in the manufacture of iron and steel.

Beds, nodular layers, and even veins of spathic iron occur in many geological formations. The veins are generally small and of little value. Among the most valuable deposits of spathose ore, outside the Carboniferous coal-measures, are those of Cleveland, which occur in the Middle Lias of England.

The red and brown hæmatite deposits of Bilboa, in Spain, are of great extent, and furnish about 70 per cent. of the raw ore imported into Great Britain for the manufacture of iron and steel. They occur in beds in a limestone of Cretaceous age.

The brown hæmatite deposits of the United States are of great extent and value. They embrace all the varieties of hydrated sesquioxide of iron recognised as limonite, göthite, turgite, bog-ores, etc. The principal producers are the States of Virginia, West Virginia, Alabama, Colorado, and Pennsylvania.

The Huronian and Laurentian rocks of North America contain vast deposits of magnetite and red hæmatite, which occur as huge contact-deposits and as regional metamorphic masses interstratified with the crystalline rocks with which they are associated.

The most valuable deposits of magnetic ore occur in Laurentian rocks in the States of Pennsylvania, New Jersey, New York, and Michigan.[2]

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[1] *The Mineral Resources of the United States*, Washington, 1901.

[2] *The Mineral Resources of the United States*, 1903, Washington, p. 44.

Red hæmatite constitutes 83 per cent. of the annual output of iron-ore in the United States, and continues to be supplied by the Lake Superior region. The principal sources of supply are the Mesabi Range, in Minnesota, with an annual output of 14,000,000 tons; the Menominee Range, in the States of Michigan and Wisconsin, with an output of 5,000,000 tons; Marquette Range, in Michigan, 4,000,000 tons; and Gogebic Range, 4,000,000 tons.

The annual output of the Mesabi Range has never been reached by any other iron-ore region in the world, the closest competitor being the Bilboa district, in Biscayan Spain, which produces 7,500,000 tons.

The output of iron-ore in Great Britain amounts to nearly 13,500,000 tons, being mainly spathic and hæmatite ores.

The magnetite and specular iron-ore deposits of Scandinavia, more especially of Sweden, are of great extent. They occur generally in crystalline rocks, in some districts as regional metamorphic deposits, and in others as contact-deposits genetically connected with eruptives. The total annual output is about 2,500,000 tons, the bulk of which is exported to Germany.

Iron-ores of commercial value are not very abundant in Australasia. What has been described as the most important is that at the Iron Knob and Iron Monarch, 41 miles W.S.W. of Port Augusta, in South Australia, which has been estimated to contain 21,000,000 tons of high-grade hæmatite and manganic iron.[1] In New Zealand, a large deposit of limonite occurs at Parapara; and enormous quantities of titanic ironsand are distributed along the shores of Taranaki and Patea.

Iron-ores containing less than 40 per cent. of the metal are rarely smelted, and only those containing over 50 per cent. are considered rich. A rich commercial sample of red hæmatite should contain from 60 to 65 per cent. of the metal.

A deposit of iron to become of any market value must be of great extent, must contain rich ore, be free from silica, sulphur, and phosphorus, easily smelted, situated in the proximity of coal and limestone, or so accessible to deep water that it could be transported to the smelters at a minimum cost for handling, and within easy reach of the great markets of the world.

Silica is the most deleterious matter found in iron-ores, and should not exceed 10 per cent. Sulphide-ores are of no commercial value for the production of iron, as the whole of the sulphur can only be removed by a dead oxidising roast, which is a costly operation. Iron-pyrites, however, is mined for the manufacture of sulphuric acid. Deposits of rich hæmatite are some-

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[1] H. Y. L. Brown, "Notes on the Iron and Phosphate Deposits of South Australia," *Supplementary Mining Records*, 1905, p. 6. Adelaide.

times rendered valueless by the presence of a percentage of sulphide-ore.

Arsenical pyrites is generally of no value as a source of arsenic, except it contains gold or tin.

The presence of sulphur, copper, or arsenic in iron-ores should in no case exceed 0·10 per cent. The coke available for smelting must not contain sulphur exceeding 1 per cent.

Iron-ores for the manufacture of acid steel must be practically free from sulphur or phosphorus. On the other hand, ores rich in phosphorus may be used for the manufacture of basic steel. In normal blast-furnace work nearly the whole of the phosphorus present in the ore goes into the pig.

For steel-making purposes the relative value of iron-ores, as regards their phosphorus-contents, depends on the process in view. For the Bessemer acid process, ores rise in value in proportion as the phosphorus is low, the maximum being about 0·03 per cent.

For the Bessemer basic process the valuation is the reverse. An average sample of pig for the basic process contains :—

	Per cent.
Silicon, . . .	0·50–1·00
Sulphur, . . .	0·05–0·15
Manganese, . .	0·35–2·00
Phosphorus, . .	1·00–3·00

Ores containing a phosphorus-percentage between the above limits are suitable for foundry-work, in which, however, an excess of phosphorus is very objectionable.

LEAD.

The most valuable and abundant ores of lead are galena and cerussite, which are generally found in veins in limestones, calcareous slates, and sandstones, and occasionally in gneiss, mica-schist, and andesite. Cerussite in only found in the shallow parts of lead-mines. Galena usually contains a small proportion of silver, varying from 2 oz. to 3 oz. to hundreds of ounces per ton, and is commonly associated with blende and pyrite.

The world's production of lead amounts to about 1,000,000 short tons, of which the United States' domestic output is equal to 26 per cent. of the whole. The other chief producers of lead are Spain, Germany, Mexico, and New South Wales.[1]

The Broken Hill Proprietary Company (Limited), in New South Wales, is the most productive lead-mine in the world.

Lead-ores are purchased by smelters on the fire assay.

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[1] *The Mineral Industry*, vol. xiii, 1904.

MAGNESITE.

This mineral is generally found in veins and masses in serpentine. The world's supply comes principally from Styria, in Austria, the Island of Eubœa, in Greece, and California.

Calcined magnesite is extensively used in the manufacture of bricks for lining electric and basic-steel furnaces, in the manufacture of paper-stock in the sulphite process, in the production of Epsom salts, magnesia, and carbon dioxide for the carbonating of mineral waters, etc., and as a non-conducting material to prevent loss of heat from boilers, steam-pipes, etc.

The market value of crude magnesite is about £1 per ton.

MANGANESE.

The principal ores of manganese are the oxides, psilomelane and pyrolusite. They are generally found in superficial masses, or in beds, veins, or masses, in slates and slaty shales, often associated with hæmatite.

Rich manganese ores, containing over 70 per cent. of the oxide, are used for making ferro-manganese, which contains about 80 per cent. of manganese, and is then in a convenient form for using in Bessemer and Siemens plants.

Silica in manganese ores should not exceed 12 per cent. The best ores contain less than 0·10 per cent. of phosphorus; but on the London metal-market the value of the ore is not seriously affected even if the percentage reaches 0·20. Beyond this limit it diminishes the selling-value of the ore.

A few years ago, when spiegeleisen was used extensively, there was a good demand for manganiferous-iron ores containing 20 to 30 per cent. of manganese and about 30 per cent. of iron.

Some manganese-ores contain sufficient silver to make them more valuable for their silver-contents than for the manganese.

Pyrolusite of high grade, say over 70 per cent., is used to a small extent in chlorination-works, and for the manufacture of bleaching-powder. For these purposes it must be as free from carbonates as possible.

The great manganese-producing countries are Russia, United States (where the bulk is raised in Michigan and Wisconsin), India, Brazil, Chili, Spain, Germany, and Turkey. The total output in 1904 amounted to nearly 2,000,000 tons, of which the United States produced about a third and Russia about a third.

The Russian output is mainly derived from Miocene sandstones and clays in the Caucasus. The price varies from 7d. to 11d. per unit.

Mica.

Mica is a constituent of many rocks, but only possesses a commercial value when it occurs in blocks or masses that are capable of being split into sheets a square inch or more in size.

The valuable deposits are not abundant, and occur generally in pegmatitic veins in granite, and in micaceous gneiss in hornblende and mica-schist. The veins vary from a few inches to several hundred feet thick.

These pegmatite veins, or dykes, as some writers suppose them to be, consist of the three essential minerals—quartz, felspar, and mica—in varying proportions. They commonly resemble a coarse granite, and in general the best mica is found in those veins in which the constituent minerals have crystallised in large masses. Where the felspar and quartz are in small masses, the mica is usually of little value. The Canadian mica is found in apatite.

Valuable mica occurs in the vein in rough crystals, called blocks or *books*, sometimes evenly distributed throughout the mass, at other times near the contact with the country-rock.

Mica when found on the surface is soft and cracked. Clearer and better-coloured mineral is found lower down in the solid; and the harder and more uniform the rock-formation, the better is the mica in colour and substance. In other words, the quality improves with the depth.

Veins under 2 feet in width seldom contain mica of commercial value, except as scrap-mica.

As a general rule not more than 10 per cent. of the mica mined is capable of being cut into plates, the balance being waste or scrap-mica. In some mines in the United States the yield of sheet-mica is less than 3 per cent.[1]

India and Canada are the chief sources of the mica used in Europe and the United States. The latter country contains mica-deposits in many places, but few are of commercial value, and at present the supply for domestic use is mainly derived from India.

In the mica-mines of Bengal in India, the best mica is found in rock. The greatest demand there is for sheets of the ruby-coloured variety, from 3 square inches upwards.

Sheet mica is largely used for furnace and stove windows and doors, lamp-protectors, and insulators for electrical machinery. For furnace and stove doors and windows the material must be clear and free from spots. The choicest is in blocks of wine-colour, white mica being preferred next. Biotite or black mica is of little value. The standard sizes for the purposes stated above range from 1½ in. by 2 in. up to 8 in. by 10 in. Smaller sizes

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[1] *Mineral Resources of the United States*, p. 874. Washington, 1901.

seldom pay for mining and preparation. Large size and fineness of grain are essential characters.

The bulk of the mica placed on the market is used for electrical purposes, principally in the construction of dynamos, alternators, transformers, etc. For these uses the sheets must be flexible, free from cracks, capable of withstanding high temperatures, and must be non-conducting, a low percentage of iron being an essential for the latter. Colour is of little moment, but perfect cleavage is of the highest importance, as "electrical mica" must be of uniform thickness, and is often gauged to the thousandth part of an inch.

The following communication, received by the Agent-General, in London, for South Australia, from Messrs Nathan & Co., of London, gives some useful particulars as to the price and market condition of mica [1]:—

"All the sizes which the native crystal will yield are at present readily saleable by auction at prices ranging from 3d. per pound for 2 in. by 3 in., to 7s. 6d. per pound for 8 in. by 12 in. Thickness must not exceed $\frac{1}{8}$ in. Anything from $\frac{1}{16}$ in. to $\frac{1}{8}$ in. is saleable. All qualities are saleable, but it is obviously impossible to give an estimate of probable prices, as no two properties yield precisely similar mica, and it would be necessary to see a case or two of the actual stuff before anything approaching a final judgment could be passed upon it.

"One or two important points may be made. The mica crystals, after being split, may be trimmed with ordinary hand-shears, all cracked edges being removed. Do not waste the material by aiming at regularity of shape, but, as far as possible, without such waste, remember that rectangular plates are preferred.

"The chief thing to secure is sound area without cracks, for it is obvious that even microscopic cracks would militate against a material to be used as an electric insulator.

"The next in importance is to secure a perfectly flat surface on splitting the mica into sheets. Any 'lumps' or unevenness between the laminæ are due to hydration or often to metallic insertion, and the latter shows itself in spots. Mica with metallic insertions is used for a variety of purposes, but is useless for insulating.

"Summarising:—

(*a*) Avoid marginal cracks.
(*b*) Split to a thickness of $\frac{1}{16}$ in. to $\frac{1}{8}$ in.
(*c*) Avoid uneven plates as far as possible.
(*d*) Cut in rectangular plates as far as possible.
(*e*) Throw out broken plates altogether—they will not pay freight and charges."

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[1] *The New Zealand Mines Record*, February 1905, p. 299.

For some purposes small irregular pieces of mica, otherwise useless, are cemented together, and built up into sheets of any desired size and thickness.

Ground mica is used as a lubricant and for decorative purposes.

The greatest care must be exercised in the preparation of mica for the market.[1] The sheet should be about $\frac{1}{8}$ in. thick, and cut cleanly and sharply into rectangular shapes if possible.

The plates should be trimmed so as to cut away any crumpled or flawed pieces, and sorted according to their colour.

The price of mica varies according to its size and colour. It rises rapidly with increase of size; thus English price lists quote sheets 2 in. by 6 in. at 2s. 6d. per lb., and 3 in. by 6 in. at 6s. 6d. per lb.

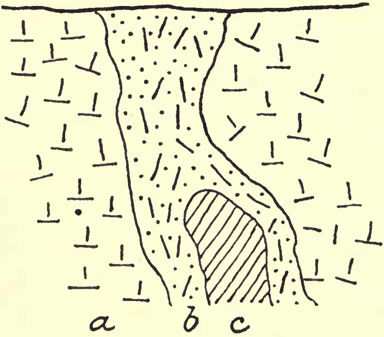

FIG. 69.—Section through Pegmatite Vein. (After H. K. Scott.)

a, Metamorphic schist; *b*, decomposed pegmatite with mica books; *c*, quartz.

MOLYBDENUM.

The commercial ores of this metal are molybdenite, the sulphide; molybdite, the yellow oxide; and to a small extent wulfenite, the molybdate of lead.

Molybdenite occurs in beds, or disseminated in scales throughout crystalline rocks such as granite, gneiss, and granular limestone. It is produced in commercial quantities in California and Canada. In the Haliburton district, in Ontario, it occurs in quartz veins, commonly associated with pyrites, pyrrhotite, and chalcopyrite.

At Wolfram Camp, in the Hodgkinson Goldfield, Queensland, molybdenite has been found in payable quantities in clean white

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[1] H. Kilburn Scott, "On the Occurrence of Mica in Brazil and on its Preparation for the Market," *Trans. Inst. Min. and Met.*, vol. xi., 1902–3.

quartz veins traversing a grey biotite-granite. It is associated with wolfram and native bismuth. The molybdenite and wolfram occur in large masses scattered through the quartz matrix, and are separated by hand-dressing.

At Jeffs Camp, in the same district, the outcrops consist of *blows*, or roughly circular or oval-shaped outcrops of quartz carrying wolfram and bismuth. The molybdenite does not generally appear until a depth of 10 feet or 12 feet below the surface has been reached.[1]

The *blows* when followed downward develop into irregular pipe-shaped masses surrounded on all sides by granite, in places vertical and in others dipping at flat angles. When the quartz has been extracted there remain only the empty pipes or vents in the granite.

Molybdenum is used for the production of ammonium molybdate, in the preparation of *blue carmine* for colouring of porcelain, and in the production of a ferro-molybdenum alloy which is in demand for the manufacture of a special steel.

In 1903 Queensland exported 11 tons of molybdenite, valued at £1320, equal to a value of £120 per ton. Buyers require ore containing not less than 45 per cent. of MoS.

MONAZITE. (See "Thorium.")

NICKEL.

The most valuable and abundant ores of nickel are garnierite, the nickel-magnesium silicate, found in New Caledonia, containing from 7 to 10 per cent. of nickel; and nickeliferous pyrrhotite, found in Canada, containing an average of 2·62 per cent. of nickel.

The price of mining garnierite, transporting to Europe, and reducing to metal is about 1s. per pound of metal produced, and of pyrrhotite, about 1s. 4d. per pound of metal.

The principal nickel-mines in Europe are situated in Norway and Sweden, the common ore being nickeliferous pyrrhotite. In Norway the ore is found in a contact-deposit between schistose quartzite and gabbro; and in Sweden in large veins in granite, associated with other sulphides, especially copper-pyrites. The oxidized ores of New Caledonia occur in decomposed serpentine.

At present Canada is the largest producer of nickel in the world. The development of the nickeliferous pyrrhotite in the Sudbury district, at Ontario, on the Canadian Pacific Railway,

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[1] Walter E. Cameron, "Wolfram and Molybdenite Mining in Queensland," *Geological Survey Report*, No. 188, Brisbane, 1904, p. 7.

has been attended with great success during the past few years, and the production of nickel has been so large that the monopoly so long enjoyed by the New Caledonia mines has been completely broken up.

In addition to nickel, the Sudbury ore contains copper about 2·8 per cent., and cobalt about 0·8 per cent., and a little platinum, about 1 oz. in 1000 lb. of nickel matte.

In the Sudbury district there is no regular vein-system. The ore-bodies occur separately, or in detached groups.

The deposits are commonly lenticular, pinching out in both directions and conforming to the general strike of the enclosing Huronian schists. The ore always occurs in, and contains fragments of, a basic and altered eruptive of the gabbro type relative to norite.

According to C. W. Dickson[1] the ore-bodies occur either well within this eruptive or at its contact with the other prevailing rocks of the district, namely, granite or granitic-gneiss, quartzite, or the metamorphosed representative of a series of basic sedimentaries, now termed "greenstones" by the Survey of Canada.

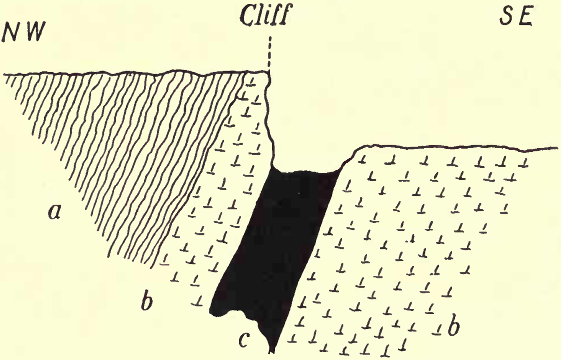

FIG. 70.—Section of Ore Deposit at Copper Cliff. (After J. H. Collins.[2])
a, Huronian schists ; *b*, Diorite (norite) ; *c*, Pyritic ore-body.

Three main belts of these norites and associated micro-pegmatites are now recognised, designated as the Northern, Middle, and Southern belts respectively. They are, at present, mapped as separate, but genetically and mineralogically they are essentially identical. Economically the Southern belt is the most important.

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[1] C. W. Dickson, "The Ore-Deposits of Sudbury, Ontario," *Trans. Am. Inst. M. E.*, vol. xxxiv. p. 3, 1904.

[2] J. H. Collins, *Quart. Jour. Geo. Soc. London*, vol. xliv. p. 834, 1888.

The genesis of the pyrrhotite of Sudbury is still a question of doubt. According to some writers, including Vogt, it is due to the development of magmatic differentiation in a cooling rock-magma. That many deposits of magnetite, chromite, and corundum have originated in this way is almost certain; but that metallic sulphides can separate out as primary constituents of a rock-magma is still open to doubt.

Philip Argall[1] considers that the nickel and copper were leached out of the norite in which they were originally formed and concentrated along zones of fracture by a process of replacement, a view supported by Professor Beck[2] of Freiberg, who maintains that the brecciated nature of the ore must have been due to deposition during, or after, the metamorphism.

The most important use of nickel is in the manufacture of nickel-steel, containing about 3½ per cent. of nickel. Considerable quantities are used for plating iron goods, and in the coinage of the United States and many European countries.

OIL-SHALE.

This occurs in beds or layers as members of a stratified formation. It yields mineral oil by slow distillation.

The origin of the hydro-carbonaceous matter in these shales is somewhat obscure. In many cases it has been shown by microscopic observation to be due to accumulations of gelatinous algæ which lived in shallow fresh-water lakes and lagoons.

The shale-deposits in the Lothians of Scotland are of great extent, and of poor quality. The Broxburn[3] shales yield from 24 to 30 gallons of crude oil and 42 lbs. of ammonium sulphate per ton, while the Drumshoreland shales yield 20 gallons of crude oil and about 60 lbs. of ammonium sulphate. The industry is maintained by the production of bye-products.

The Permo-carboniferous shales of New South Wales are of high grade, but occur generally in thin seams. They are now nearly exhausted.

The oil-shales of New Zealand are of Middle Tertiary age. They are, in places, of great extent, but generally poor and low in ammonia.

PETROLEUM.

Mineral oil is found in geological formations of all ages, but in commercial quantities occurs chiefly in two horizons—namely, the Middle Palæozoic and lower half of the Tertiary.

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[1] *Proc. Col. Sc. Soc.*, December 1893.

[2] R. Beck, *Lehre von den Erzlagerstätten*, 1901.

[3] *Trans. Inst. Min. Eng.*, vol. xxii. p. 581, 1902.

In America it is found mostly in rocks ranging from Silurian to Carboniferous, and in Eastern Europe and Asia in rocks of the Eocene and Miocene periods.

Generally speaking, petroleum is found beneath the crowns of anticlinal folds, saturating porous uncemented sandstones.

The genesis of natural oil has not yet been satisfactorily explained. The French school maintain that it is chemical, resulting from the reaction of alkali metals at a high temperature on steam and carbon dioxide. Crude petroleum, in many respects the same as natural oil, was prepared synthetically by Berthelot in this way. The hydrogen of the water and the carbon of the carbon dioxide having been deprived of their oxygen, unite to form an oily substance closely resembling rock-oil.

The destructive distillation of shale, peat, wood, and animal matter produces an oil having the same carbon and hydrogen compounds as the natural oil of Pennsylvania. But, on the other hand, oils have been found in Canada, Tennessee, and elsewhere of a different composition, filling cavities in a richly fossiliferous rock. The rock in which the oil is imprisoned is a thickly bedded limestone of Silurian age, probably deposited in a deep sea swarming with animal life. It is generally assumed that the oil, which can apparently be liberated only when the rock is broken, is indigenous to the rock in which it occurs.

The porous oil-bearing sandstones of Pennsylvania are underlain comformably by a formation of shale more than 1000 feet thick, containing fossil animals and fossil seaweed in vast quantities. Experiments have shown that this fucoidal shale, when subjected to slow destructive distillation, in some cases yields as much as 50 gallons of crude oil to the ton of rock. This oil in many respects can hardly be distinguished from the natural crude oil.

The commonly accepted theory is that petroleum is a natural distillate from carbonaceous or animal remains imprisoned in rocks. The distillate would naturally rise into the overlying strata, where it would become condensed; and where the rocks were porous it would accumulate.

The heat required for the distillation may have been derived from igneous intrusions, plutonic or volcanic, from the reactions of deep-seated metamorphism, or from the heat due to pressure in cases where the strata have been involved in deep crust-folds.

Mineral oil is produced in vast quantities in the United States, particularly in the States of Pennsylvania, Texas, Ohio, California, and Indiana; in the Baku region, in Southern Russia; Galicia, in Austria; Roumania, Burmah, Borneo, Sumatra, and Java.

The output of the Appalachian oil-fields in Pennsylvania and

West Virginia amounts to about a third of the total production of the United States.

PHOSPHATE ROCK.

Mineral phosphates are now used in vast quantities as fertilisers. They are found in many countries, the chief producers being Canada, United States, and Algeria. The output of Florida and South Carolina, besides supplying the market of the United States, is able to furnish large quantities for export.

Of late years the American industry has been seriously affected by the large output of the Algerian phosphate beds, which produce a high-grade mineral containing from 63 to 65 per cent. of phosphate of lime, and a second grade containing from 55 to 63 per cent.

The formation of phosphate-deposits is generally believed to have been due to the leaching or lixiviation of phosphate-bearing rocks by waters containing carbonic and other organic acids, followed by the subsequent concentration of the phosphate under favourable conditions. In some cases they deposited their calcium phosphate in caverns formed in limestone or calcareous sandstone, and the subsequent removal by solution of the walls of the caverns, either wholly or partially, left the phosphate in the remaining sands

It is of interest to note that the apatite beds and veins of Ottawa, in Canada, occur in rocks of Laurentian age. The brown rock-phosphate of Tennessee is believed to have been derived from the underground weathering of certain phosphatic layers in the Lower Silurian limestone which forms the basin of middle Tennessee. These layers do not occupy an unvarying stratigraphical position, but occur in various horizons in the Lower Silurian formation.[1]

The phosphate-deposits in the South of England, in France, and Belgium occur associated with Cretaceous chalk. Those of Algeria and Tunis are of Eocene age, the phosphates occurring in nodules in marl or as phosphatic limestone. In Algeria, which has been estimated by M. Chateau, a French mining engineer, to contain from 150,000,000 to 300,000,000 tons of phosphate rock, it is considered risky to mine rock containing less than 60 per cent. of the tricalcic phosphate.[2]

The celebrated phosphate-deposits in Peninsular Florida occur in detached pockets lying on the uneven surfaces of an Eocene limestone, and in Western Florida on Miocene limestone.

[1] William Hayes, *Annual Rept. U. S. Geol. Survey*, p. 633, 1898–99.

[2] *Memoirs of the French Society of Civil Engineers*, August 1897.

The once-famous beds of South Carolina are considered to be of Post-Pliocene age.[1]

The phosphate of lime formerly worked at Aruba and Sombrero, in the West Indies, was originally a coral limestone converted into a phosphate by the percolation of water containing phosphoric acid derived from the overlying deposits of bird-guano.

A valuable deposit of rock-phosphate was discovered in 1901 at Clarendon,[2] in the Province of Otago, in New Zealand. It occurs in chemically eroded pockets and hollows on the upper surface of a Miocene limestone, as shown in the following diagram :—

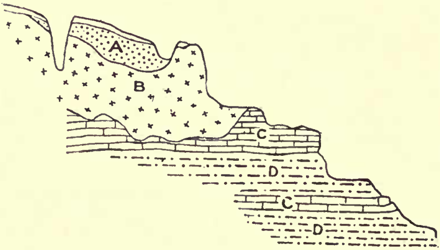

FIG. 71.—Section of Clarendon Rock-phosphate.

A, Loose phosphatic sands ; B, rock-phosphate ; C, limestone, generally glauconitic ; D, glauconitic greensands.

The geological conditions which accompany and doubtless determine the existence of workable deposits of phosphate are the presence of a phosphate-bearing formation at the surface, lying in a favourable position for underground weathering over considerable areas, and subsequent concentration of phosphate by replacement or secondary enrichment.

The phosphate deposits in Yorke's Peninsula, South Australia, occur in caves and fissures in a Cambrian limestone. They are reported to be of large extent, high grade, and favourably situated for working.[3]

To become of commercial value a phosphate-deposit should fulfil the following requirements :—

(1) Be of such magnitude as to justify the erection of tramways and other surface-plant necessary for development and winning of mineral.

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[1] Penrose, *U.S. Geol. Survey Bulletin*, No. 46, p. 60, 1898.

[2] J. Park, "The Rock-phosphates of Otago," *Trans. N.Z. Inst.*, vol. xxxv. p. 391, 1902.

[3] H. Y. L. Brown, "Notes on the Iron and Phosphate Deposits of South Australia," *Supplementary Mining Records*, 1905, p. 5. Adelaide.

(2) Be of high grade, averaging not less than 50 per cent. of tricalcic phosphate before dressing.
(3) In a position easy of access to a railway or seaboard.
(4) Easy to win—that is, in a position in which it can be worked water-free by open cuts and quarrying. The overburden must also be shallow and easily removed. When it exceeds 20 feet the cost of stripping runs away with the profit.

It is only in exceptional cases that it pays to mine phosphate by underground workings. At Ross Farm, in Pennsylvania, during the year 1899, 2000 long tons were mined from a stratum 30 feet thick, 4000 feet long, and inclined at an angle of 60° from the horizontal. The stratum was mined to a depth of 300 feet below water-level, and averaged about 56 per cent. of phosphate. Here the matrix consisted of a yellow marl, easily and cheaply broken. The producers, however, did not compete in distant markets with the higher grades of phosphate from South Carolina, Tennessee, and Florida, but looked only for a remunerative local market.[1]

PLATINUM.

This valuable metal is generally found sparingly disseminated in olivine, in olivine-gabbro, serpentine, and other ultra-basic rocks in Russia,[2] Germany, France, and New Zealand. It is found in gold placers in many parts of the world in small quantities. It is commonly associated with chromite of iron, which also has a preference for magnesian eruptive rocks.

Platinum, as sperrylite, the arsenide of platinum, occurs in the cupriferous nickel-ores of Sudbury, in Canada, and in the copper-ores of Rambler Mine, in the Medicine Bow Mountains of Albany County, in the State of Wyoming. Refined methods of analysis have shown that this metal in minute traces exists in cupriferous sulphide-ores in many parts of the world.

Hundeshagen [3] records the occurrence of platinum in Sumatra in wollastonite which is associated with schists, granite, and augite-diorite. He thinks that the ore-deposit was originally a big lens of limestone imbedded in the schists, subsequently altered to garnet and wollastonite, and mineralised by hot solutions carrying copper, gold, and platinum.

The world's supply of platinum is mainly derived from placer deposits in the Ural Mountains, mostly situated on the western

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[1] *21st Annual Rept. U.S. Geol. Survey*, p. 494, 1899–1900.
[2] J. F. Kemp, *Bull. U.S. Geol. Survey*, No. 193, p. 72.
[3] L. S. Hundeshagen, *Trans. Inst. Min. and Met.*, vol. xiii. 1904.

slopes. In 1904, the output of Russia amounted to 14,230 lbs., equal to about 90 per cent. of the world's production. In September of that year two lumps of platinum were found at Krestowosdwischensk, one weighing 756 lbs., the other over 360 lbs. A small part of the domestic requirements of the United States is obtained as a secondary product from the gold-placers in Trinity and Shasta Counties in California.

Some of the gold-placers of Colombia, Alaska, Siberia, Australia, and New Zealand contain platinum, but rarely in payable quantity.

The Fifield Goldfield, in New South Wales, yielded, in the year 1902, 375 oz. of platinum, valued at £750. In the same year Russia produced 234,478 oz., which represented over 90 per cent. of the world's output. The balance is mainly furnished by the State of Colombia, in South America.

QUICKSILVER.

The only valuable ore of this metal is cinnabar, the sulphide, which occurs in veins traversing slates and sandstones, or disseminated in altered andesites. It is, however, found in rocks of all ages and all kinds, but shows a preference for sandstones, and in most cases is found along lines of country that have been affected by volcanic disturbances.

Some cinnabar has been deposited from hot solutions brought up by volcanic springs. At Ohaeawai Hot Springs, in New Zealand, the cinnabar-deposits were formed in this manner, as probably were those of Almaden.

The principal quicksilver-producing mines at the present time are situated at Almaden, in Spain, New Almaden in California; Idria, in the Provence of Carniola, in Austria; and Russia.

The average yield of the Almaden ores is from 7 to 10 per cent., but ores containing as little as 1 per cent. have been mined with profit. The grade of the Russian ore is generally under 1 per cent.

SILVER.

Among the principal ores of silver are kerargyrite, or horn silver, embolite, and argentite, the subsulphide. Large masses of the two former were found at the Broken Hill mines, in New South Wales, disseminated throughout kaolin clay.

Masses of native silver have been found in Saxony and Hartz Mountains, but the largest masses were discovered in Mexico and Peru, and in the Lake Superior mines, associated with native copper.

Silver-ores are commonly found in granite, gneiss, mica-schist, and sandstone, and frequently in andesite and trachytic rocks.

All galena and some copper-ores contain more or less silver. The great bulk of the silver of commerce is derived from silver-lead ores, the balance being mostly obtained from dry silver-ores, from copper-ores, and from gold alloyed with silver.

The gold extracted from veins in older Tertiary eruptives usually contains a large proportion of silver.

The great silver-producing States in America are Colorado, Montana, Utah, and Idaho, where the bulk of the silver is derived from silver-lead ores. The dry ores of the Comstock lode in Nevada were for many years the source of a large output of silver.

The yield of Colorado is nearly one-third of the United States' production, mostly derived from the silver-lead ores in Leadville district.

The silver-lead ores of Butte district, in Montana, are the source of the bulk of the production of that State.

Among the most productive silver-mines in the United States is that of the Daly West Mining Company, which, in 1902, produced 3,575,796 oz., equal to a third of the Utah output.

In 1902 the silver produced in Mexico exceeded that of the United States. It was derived from silver-lead and dry ores, and largely as a by-product from the treatment of copper and pyritic gold-ores.

The bulk of the 10,000,000 oz. produced annually in Australasia is extracted from the silver-lead ores of Broken Hill. For the year ending the 30th November 1902 the Broken Hill Proprietary Mine alone produced 5,477,143 oz. of silver.

SLATE.

The essential requirements of a roofing-slate are hardness and toughness. The tests recommended are as follow :—

(1) Weigh the dry slate. Immerse in water for twenty-four hours. Take out, wipe dry, and reweigh. Note the amount of water absorbed.

(2) Place the dry slate on its edge in water so that half the surface is covered ; if it be of poor quality, moisture will creep by capillary attraction into that part of the slate which is above the water-line.

(3) Breathe on the slate. If a strongly marked argillaceous or clayey odour is detected, it is safe to assume that the slate will disintegrate easily under atmospheric influences.

The slates should be of uniform colour throughout. Spotted slates are often inferior in durability. Marcasite is objectionable in slate, as it oxidises readily. Cubical pyrites does not oxidise readily, and is therefore not so objectionable.

A good slate should be capable of being split into smooth thin laminæ parallel to the planes of slaty cleavage.

The specific gravity of slate varies from 2·7 to 2·9.

Large quantities of slate are quarried in the United States, France, and England.

SULPHUR.

The sulphur of commerce is derived from native sulphur and pyrites.

Native sulphur is common in most volcanic regions, more especially around the vents and fissures, both active and extinct.

The world's production of native sulphur in 1904 amounted to 600,000 tons, of which Italy produced over 93 per cent. The balance is mined in Japan, United States, France, Austria, and Greece.

The price of crude sulphur varies according to quality from £3 to £4 per ton. The sulphur is principally used in the manufacture of sulphuric acid.

The principal producers of pyrites for the manufacture of sulphuric acid are Spain, France, United States, Germany, Norway, Italy, Canada, and Russia.

TALC.

This mineral in its fibrous and massive forms occurs in beds and lens-shaped masses in talcose and chloritic schists. It is often associated with granular limestone.

The massive form is generally known as steatite or soapstone.

Talc is used as flour-talc, and as pieces cut into various shapes. The flour is used as a base for fireproof paints, for electric insulators, for boiler and steam-pipe coverings, as a base for dynamite, in the manufacture of wall-paper, for leather dressing, and as a lubricant.

The harder varieties of soapstone are cut into hearthstones, linings for furnaces, laboratory tables, ovens, pencils, and gas-tips. The talc produced in the United States is valued at about £3, 5s. per ton.

THORIUM.

This rare and valuable metal is obtained from the mineral monazite, which is essentially an anhydrous phosphate of the rare earthy metals cerium, lanthanum, and didymium, having the formula $(CeLaDi)PO_4$. A small but variable proportion of thoria (ThO_2) is nearly always present.

Monazite is described by J. H. Pratt[1] as light-yellow, honey-yellow, reddish, brownish, or yellowish-green in colour, with a resinous to vitreous lustre. It is translucent to subtranslucent; brittle, with conchoidal fracture, and hardness from 5 to 5·5; monoclinic, and in crystals up to 2 in. long. Perfect crystals are generally small, from $\frac{1}{8}$ in. to $\frac{1}{16}$ in. downward to those of microscopic size. The specific gravity is high, and ranges from 4·64 to 5·3.

It is incompletely insoluble in hydrochloric acid, but completely and readily in sulphuric acid. If oxalic acid is added to the very dilute filtered sulphuric acid solution, or to the solution obtained by fusing the mineral with soda, and if the mass is treated with water and the residue filtered and dissolved with hydrochloric acid, a precipitate is obtained, which, upon ignition, becomes brick-red, due to the presence of cerium oxide.

Before the blowpipe the mineral turns grey, but is infusible. If heated with sulphuric acid it colours the flame bluish-green, due to phosphoric acid.

Monazite is found in granite, gneissic rocks, and mica-schist in the Maritime Mountains of Brazil, in South Mountain region of North Carolina, and many other places, but only in minute quantity. The monazite of commerce is derived from sands or placers resulting from the denudation of the mineral-bearing rock.

The Brazilian deposits occur as beach sands.[2]

Thorium is chiefly used in the manufacture of mantles for incandescent gaslights.

The value of monazite is about 4d. per pound.

TIN.

The only ore of this metal of commercial value is the oxide, cassiterite, which occurs in lodes, beds, and stockworks, and in alluvial drifts.

Tin-ore is found in granite, felspar-porphyry, and other acid eruptives, and in sedimentaries which have been intruded by granite, etc.

At Mount Bischoff,[3] one of the greatest tin mines on the globe, the Palæozoic slates and sandstones are intruded by dykes

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[1] Joseph Hyde Pratt, *Mineral Resources of the United States*, p. 1163, Washington, 1904.

[2] *Loc. cit.*, p. 951.

[3] Sydney P. Fawns, "Notes on the Mount Bischoff Tin Mine," *Trans. Inst. Min. and Met.*, Pamphlet, p. 16, London, 1905.

of porphyritic felsite which carries topaz both crystalline and amorphous. The topazisation was probably a pneumatolytic process proceeding from deep-seated granite. The felspar of the ground mass is replaced by topaz. The analysis recorded by Baron Von Groddeck showed no alkali. The rock consisted practically of quartz, topaz, and tin. Wolfram does not occur in payable quantity in the topaz tin-ore.

The common associates of tin-ore are wolfram, quartz, mica, and tourmaline.

About 65 per cent. of the world's supply is derived from the tin-placers in the Straits Settlements and Dutch East Indies, where the tin-bearing gravels cover hundreds of square miles.

The world's annual production is about 100,000 tons.

Tin containing 5·5 per cent. of arsenic is useless for commercial purposes and requires further purifying.

Tin-ore is bought by the smelters from the results of the dry assay, and is subject to certain schedule deductions.

TUNGSTEN.

The principal ores of tungsten are scheelite, the tungstate of lime; wolfram, the tungstate of iron; and megabasite, the tungstate of manganese.

Wolfram is usually associated with tinstone. Scheelite occurs in veins in schists and sandstones, generally associated with quartz. When the vein-stuff contains gold or silver, as often happens, the scheelite can be produced very cheaply as a by-product.

The best-known deposit of megabasite is that in the Ima Mining Company's property at Patterson Creek, in the state of Idaho, where it occurs with wolfram in a vein varying from 5 feet to 15 feet wide, and assaying from 5 per cent. to 50 per cent. of tungstic acid.

The principal sources of the world's tungsten are England, Austria-Hungary, Saxony, Germany, New South Wales, and Queensland.

The price varies with the quality of the ore. German and English buyers give from 7s. to 8s. per unit.

In the United States prices are somewhat higher, the value of scheelite containing from 45 per cent. to 55 per cent. of tungstic acid being about 8s. per unit, while ores containing from 55 per cent. to 65 per cent. of tungstic acid command 10s. per unit of scheelite. The ferro-tungsten ore wolfram is mainly produced in Cornwall (England), Hungary, New South Wales, and Queensland. It is sold on the tungstic acid basis. Wolfram to be marketable must be brought to an average of 50 to 70 per cent. of tungstic acid. It is essential that the ore be free, or nearly so, from phosphorus and sulphur, but the presence of carbon and silica will not be considered injurious. At present an ore averaging 60 per cent. WO_3, and containing not more than 0·25 per cent. phosphorus, and 0·01 per cent. sulphur, can be sold in New York at 28s. per unit of tungstic acid, equal to £84 per long ton.

A typical ore, used by German steel works, analyses from :—

WO_3,	60–76
FeO,	8–10
MnO,	9–12
CaO,	0·4–1

Buyers as a rule do not care to handle ore running under 40 per cent. of tungstic acid. Therefore to be brought up to a marketable grade the ore must be crushed and concentrated. High-grade ores can be bagged as they come from the mine, or their grade may be improved by hand-sorting; but quartzose ores can only be made marketable by wet-crushing and concentration.

The wolfram produced in Queensland is of very high grade, and for a time commanded as much as £140 per ton.

The chief use of tungsten is in the manufacture of tungsten steels, which possess the special property of self-hardening. Recently tungsten has been added to a copper-aluminium alloy, to which it imparts greater strength and toughness. Tungstate of soda is used in conjunction with starch for rendering light fabrics non-inflammable. It is also used by dyers as a mordant, for hardening plaster-of-paris, and to a small extent in the arts.

ZINC.

The principal source of the zinc of commerce is the sulphide, sphalerite or blende, and to a less extent the carbonate, calamine.

Zinc-ores are commonly associated with galena, pyrites, and often copper.

The principal zinc-producing countries are Germany, United States, Belgium, Italy, Sweden, England, and Austria.

The ores of Broken Hill, in New South Wales, contain a large percentage of zinc, the economic extraction of which has proved a difficult problem.

CHAPTER VIII.

MINE-SAMPLING AND ORE-VALUATION.

CONTENTS :—Sampling Equipment—Sampling Intervals—Record of Samples —Breaking the Sample—Sampling—Reduction of Sample—Assay of Samples—Calculating Value—Future Prospects—Sample Values and Mill Values—Sampling Dumps and Heaps.

IN the majority of mines sampling proceeds simultaneously with the mine development, the results being recorded on *assay plans*, which are generally longitudinal or stope plans. Where the sampling during development has been carefully and systematically done, the averages should approximate those obtained by the mine-examiner.

Sampling Equipment.—This includes new sample bags of canvas or stout calico, say 14 in. long and 9 in. wide; a canvas sheet, about 6 ft. long and 5 ft. wide; a short-handled 4 lb. or 5 lb. hammer; a gad or two; small linen tape or foot-rule; a number of small metal tags or strips of soft wood, each with a distinctive number or mark; and a stout canvas lock-up sack for the safe custody of samples.

Sampling Intervals.—Begin the sampling of a level at the end of the main cross-cut, or at some point easily located with respect to a survey station.

When the whole width of the vein or seam is exposed in the drive it is customary to sample the higher or foot-wall portion lying on the back of the level, as the lower portion may be partly underfoot, and often covered with mud and water.

Divide the level into sections of 5 ft., 10 ft., or more, according to the extent of the open ground and character of ore. Mark the divisions with chalk, or by blackening the wall with a candle-flame.

With respect to the sampling intervals, it is well to remember that a large number of small samples taken at short intervals are often more reliable than a small number of large samples taken at wide intervals.

When the ore is known to be consistent in value, and is exposed in long stretches, the sampling intervals may be 20 ft. apart; but when the vein is somewhat irregular in width and value the 5 ft. intervals will give the most trustworthy results.

Record of Samples.—Carefully measure and record the width of the vein in feet and inches at each interval.

A simple and accurate method of recording the sampling intervals, widths, and sample numbers is to draw a diagram in field-book representing a longitudinal section of the level. On this diagram, which need not be drawn to scale, all the necessary information can be shown graphically. This method has also the advantage that the assay-values can afterwards be filled in at the different intervals, thus completing the record.

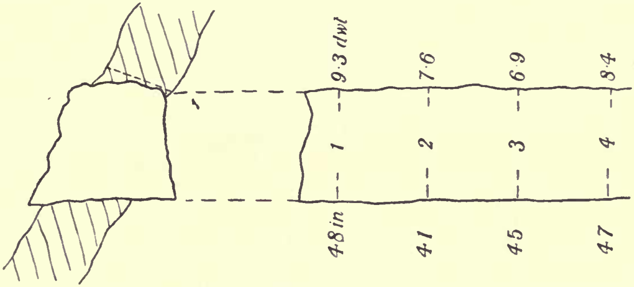

FIG. 72.—Showing Record of Widths, Values, and Sampling Intervals.

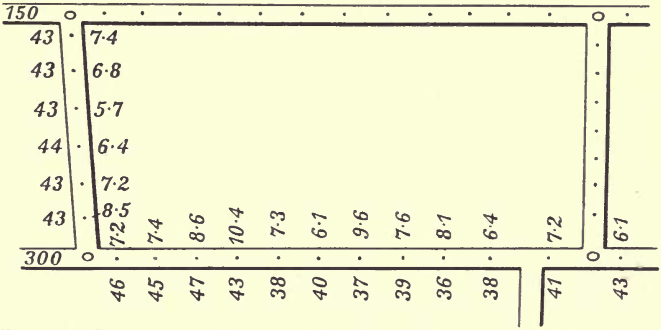

FIG. 73.—Longitudinal Section of Block between 150 and 300 feet Levels.

The widths, numbers, and values are commonly recorded on mine-assay plans in different coloured inks, according to the individual fancy of the engineer; but this is not necessary in the examiner's field-book, which is a private record.

In the above figure the widths of ore are shown in inches under the level, and the value in dwts. above the level. The sampling intervals are represented by dots.

In the Meyer and Charlton[1] Mine, at Johannesburg, the values entered upon the continuous section are not the assay values, but the recovery values which the different processes in use are estimated to be capable of recovering.

Breaking the Sample.—Dress the face down with a pick, so as to expose a fresh surface, and, if necessary, clean it with water.

With the hammer and gad break a sample at each interval, allowing the material to fall on to the canvas sheet, or into a stiff felt hat or narrow box held by an assistant.

The sample is taken from a groove cut at *right angles* to the plane of the dip; or, in other words, *across* the thickness from wall to wall, as shown in fig. 72.

In cases where the width of the vein is less than that of the level or stope, it is necessary to square the ore on the back of the level or stope in order that the true width of the vein, from wall to wall, may be exposed for sampling.

In ore of fairly uniform hardness the width of the groove will vary from 4 in. to 6 in., and from $\frac{3}{4}$ in. to $1\frac{1}{2}$ in. deep. The sample will generally weigh from 2 lbs. to 10 lbs. for every foot of vein or bed.

When the vein-matter is arranged in distinct bands of crustification—that is with a ribbon-structure—it is advisable to sample each band separately to determine where the values lie.

Wide lodes should also be sampled in widths of 2 ft. or 3 ft., as sometimes the values are carried by the foot-wall portion, sometimes by the hanging wall or by the central portion. In such cases a single sample taken from wall to wall may convey quite an erroneous impression as to the commercial value of the lode.

Where a level is driven on a wide lode, only a small portion of the ore is exposed for examination. In such cases it is customary for the management during the progress of development to cross-cut the lode at intervals of 20 ft. or 50 ft., according to the metalliferous character of the ore. These cross-cuts will afford the examiner an opportunity of sampling the lode from wall to wall in such manner as the case may require. Where there are no cross-cuts through the lode from the level, the full, or, at any rate, the payable, width of ore will generally be found exposed in the stopes.

It often happens, in the case of flat-lying veins, that the level has been driven on the footwall of the vein, or that the level has

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[1] T. A. Rickard, *The Sampling and Estimation of Ore in a Mine*, p. 174, New York, 1904.

been timbered for the stoping. In these cases there is no exposure of the ore in the level, and the samples must be obtained from the stopes overhead.

When sampling a lode composed of very soft, friable, or sugary ore, it is advisable to expose a fresh surface by cutting a groove 6 in. or 8 in. wide and several inches deep. The material from this groove is rejected, and the assay sample broken down from the fresh surface exposed in the cut.

With uniformly soft material throughout, a pick may be safely used in breaking the samples; but with hard ores, or ores containing hard and soft patches, the hammer and gad must alone be used, as the pick is liable to find the soft places more frequently than the hard, with the result that a relatively larger proportion of the soft ore is broken than of the hard.

If the softer material is richer than the harder, as it often is, manifestly the sample will be unduly enriched; but if poorer, then the sample will be impoverished. In any case the assay value will not represent the true value of the ore.

Sampling on Floor of Levels.—In cases where the ore has been stoped out above a level it may be necessary to sample the vein along the floor. Here the rails, sleepers, water, and sediment will increase the difficulties of the sampler. The blasting will have shattered the ore, and the interstices will have become filled with sediment either richer or poorer than the ore itself. In these circumstances the sampling must be conducted with much care and judgment.

Sampling Specimen Veins.—The valuation of gold-bearing veins in which the gold occurs in isolated bunches or patches at irregular intervals, or only at the intersection of cross-veins or *indicators*, is impossible by the ordinary methods of sampling. Even bulk or battery tests are not to be relied upon, as the values generally lie in a very small space. Thus, while hundreds of ounces of gold may be found in the space of a few yards, the ore for long stretches on both sides may contain no gold whatever. The valuation of such properties is a problem of almost impossible solution.

Sampling of Stopes.—Stopes are merely a succession of horizontal drives. They are sampled in the same manner as levels. Samples are broken from the back, sides, and working faces, according to circumstances.

When the width of the vein is less than the width of the stope, the vein and the rock must be sampled separately, the widths of each being carefully noted.

Sampling of Winzes.—Ore exposed in rise and winzes is valued by breaking samples at 5-feet or 10-feet intervals from grooves cut at right angles to the plane of the dip. The thickness of ore is measured and recorded on a diagram in the field-book, together with the sample number at each interval.

Reduction of Sample.—The weight of the sample broken down will vary with the width and hardness of the ore. When it is larger than the capacity of the sample-bag, the sheet must be carried to a convenient place underground, and its contents broken down to the size of a walnut. When this has been done, the sample is thoroughly mixed, formed into a very flat truncated cone, and quartered.

Two opposite quarters are rejected, being removed *completely* with all their *fines* from the sheet. The material in the two remaining quarters is then broken down to a size half the diameter of a walnut, thoroughly mixed, and again quartered. The two quarters lying in the position of the two quarters retained in the first operation are rejected and removed from the sheet.

A common method of mixing the ore on the sampling-sheet is to toss the material from one side to the other. In this process care must be taken to insure that the fines are not concentrated in one particular part of the sample, but evenly distributed throughout the whole mass before each quartering.

In three-quarterings, a sample weighing 80 lbs. will thus be cut down to 10 lbs., which is about the maximum capacity of the sample-bags.

The time required to break down a sample will depend upon the hardness and size of the lode. It seldom is less than half an hour, and may extend to several hours, depending upon the number of quarterings needed to reduce the sample to a convenient weight. The sampling of a large mine may occupy several weeks, and run into a cost of several hundred pounds.

Assay of Samples.—The whole of the sample should be dried, crushed in a rock-breaker in the laboratory to pass through a 10-mesh sieve, mixed, and sampled by quartering till reduced to a pound or two in weight, all of which should be finally pulverised, passed through a 60-mesh sieve, again mixed, and divided into two portions. One portion is handed to the assayer, while the other is retained as a duplicate sample for subsequent reference and verification if the necessity should arise.

Carelessness in the laboratory may stultify all the care exercised in the sampling underground.

If the mine-examiner submit his samples to an assayer whose qualifications are unknown to him, he should take care to be present during the crushing, pulverising, and final division of the assay samples.

The duplicate samples should be put into small calico or stout brown-paper bags, labelled, and secured in a lock-up sack, which should be removed from the laboratory.

The examiner's samples should never be submitted to the mine-assayer; and only in very exceptional circumstances should the samples be placed in the hands of an unknown assayer.

Calculating Average Width and Value of Vein.—The assay-values may be expressed in pennyweights of gold per ton; percentage of metal; or, in the case of low-valued gold or bullion, the money-value may be stated in dollars or £ s. d. per ton.

The thickness of the ore is most conveniently expressed in inches for veins up to 8 feet or 10 feet thick. Take the case of ten samples from a gold-bearing vein, as follows:—

No. of Sample.	Width of Vein in Inches.	Assay-value per Ton in Pennyweights.	Inch-dwt.
1	40	8	320
2	36	9	324
3	32	7	224
4	34	5	170
5	28	9	252
6	30	6	180
7	34	8	272
8	38	5	190
9	40	7	280
10	44	4	176
...	356	...	2388

The average width is found by dividing the sum of the widths by the number of samples. Thus, in this case we have $\frac{356}{10} = 35 \cdot 6$ inches average width.

The average assay-value is found by dividing the sum of the inch-dwt. by the sum of the widths as under: $\frac{2388}{356} = 6 \cdot 7$ dwts. per ton for a width of 35·6 inches.

When a vein contains two bands of payable ore separated by a band of no value, which cannot be sorted out economically, the average assay value is ascertained as follows:—

Let band A be 18 inches wide, and have an assay value of £2 per ton.
,, B ,, 6 inches wide and worthless.
,, C ,, 12 inches wide and worth £3 per ton.

Then $$\frac{(18 \times 2) + (6 \times 0) + (12 \times 3)}{18 + 6 + 12} = £2 \text{ per ton.}$$

If it is practicable to sort out half of the worthless band, then the average assay value of the ore will be found as under :—

$$\frac{(18 \times 2) + (3 \times 0) + (12 \times 3)}{18 + 3 + 12} = \text{£}2,\ 3\text{s. } 8\text{d. per ton.}$$

In estimating the *net profit in sight* in a block of ore, it is manifest that the recovery value, and not the assay value, must form the basis of the calculation.

High Assay Values.—A sample giving an exceptionally high assay-value may be dealt with in different ways. It may be discarded entirely and not included in the average ; or ascertain the average value with it included, and replace the original exceptional value by this average, and then calculate the average value for the average width.

For example : Five Samples gave values of 10 dwt., 20 dwt., 25 dwt., 120 dwt., and 25 dwt. per ton. The average is 40 dwt. Replace the exceptional value, 120 dwt., by 40 dwt., and then proceed with the calculation of results.

The exceptional value may represent a small patch of rich ore, or a bunch of rich ore increasing in dimensions going upwards or downwards, or even a solitary speck of gold. The most satisfactory manner of dealing with an exceptionally rich assay from a sample is to resample the vein a second time. T. A. Rickard[1] also recommends the taking of intermediate samples as a further precaution against fraud or mistake.

Future Prospects.—When satisfactory values have been obtained around a block of ground, the natural inference is that the area of ore is of the same approximate value.

Experience has shown that where a block is exposed on four sides, such inference is fair and reasonable. Where the block is exposed on three sides the inference is open to doubt.

Before arriving at a definite conclusion as to the future prospects of the mine, it is advisable for the examiner or mining engineer to carefully consider the following questions :—

(1) Is there any change of rock-formation enclosing the lode in any part of the mine? If so, what influence does this change of country exercise upon the value of the ore?

(2) Is there any indication of barren zones of ore, either in depth or horizontal extension, along the course of the lode?

(3) Are the values in the zone of oxidation likely to be maintained in the unoxidised portion?

(4) What are the probabilities of impoverishment in depth?

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[1] T. A. Rickard, *loc. cit.*, p. 42.

Sample Values and Mill Returns.—Manifestly the assay-values obtained represent only the values of the actual material broken by the examiner. The variations of value obtained at the different intervals clearly emphasise the variable value of the ore. Hence the mean values deduced from the assay-values can only be regarded, even in the most favourable cases, as close approximations.

A mining engineer with a personal knowledge of the ore and values in a mine extending over a considerable period can often so adjust his averages by the experience of the past as to make a very close estimate of the quantity and value of ore in newly developed ground in the same or adjoining mines.

The discrepancy that often exists between the sampler's estimate and the mill returns, in the case of gold-ores particularly, may be due to one or several causes, among which the following may be enumerated :—

(1) A sudden increase of width of ore without a corresponding increase of values.

(2) A sudden decrease in values ; or the payshoot may be split by a *horse* into two legs which reunite between two levels.

(3) A greater proportion of mullock or rock is sent to the mill than was contained in the examiner's samples. This is a contingency very liable to occur in the breaking of a narrow vein in the stopes, especially where the vein is less in width than the width of the breast or face. In cases where the walls of the vein are well defined and the stripping easy, the proportion of rock introduced with the ore is not likely to be very great, especially where a stretch of ore is stripped before it is broken.

(4) Imperfect tally of the tonnage of ore sent to the mill.

(5) Inadequate allowance for moisture.

The sampling of a mine for valuation purposes is most exhausting, both physically and mentally. When the work has been carried out carefully and conscientiously, the mine-examiner should be prepared to stand by his results.

The examiner must remember that he is the confidential adviser of his principals, and for that reason must keep a discreet silence about the results of his examination, and of his opinion as to the probable value of the mine.

Sampling of Dumps or Paddocks of Ore.—The stack of ore is divided into a number of small blocks by two systems of cuts or trenches passing through the ore at right angles to each other.

(*a*) Each block can now be sampled separately by picking pieces of ore from its four sides.

(*b*) Or the material excavated from the trenches can be wheeled to a clean piece of ground, spawled into small pieces, mixed, and quartered repeatedly until a sample of convenient size is obtained. Before each quartering the larger pieces of ore must be broken to half their diameter in the preceding quartering.

(*c*) Or the material from the trenches can be crushed in a rock-breaker, mixed, and quartered down till the assay sample is obtained.

Sampling Heaps of Tailings.—If the accumulation of tailings is large it should be sampled in separate sections, as large piles of sands are liable to vary considerably in value in different parts.

Stake off the heap, so as to divide it into sections about 5 yards square. Make a diagram in field-book corresponding to sections. Record the dimensions of the sections, and distinguish each section by a letter, as A, B, C, etc.

Sample each section, beginning with section A :

(1) With a sampling-iron take samples all over the section at, say, every foot or two.

(2) If there is reason to believe that the values are not the same from top to bottom, put the top material into one bag and the lower into another ; or, if necessary, separate samples can be taken for every foot of depth.

(3) If there is no sampling-iron available, holes are dug at intervals of every 4 feet or 6 feet. The sands from the holes are wheeled to a clean place, mixed, and reduced by quartering to a convenient size.

If required, the sand obtained from different depths can be kept separate.

Salting of Mines.—By "salting" is meant the illegal enrichment of the ore, with the object of giving the property a fictitious value.

The mine-examiner should be familiar with the methods adopted by unscrupulous persons, so as to be able to protect the interests of his principals.

A common method is to tamper with the examiner's samples ; and for this reason the samples should always be in safe custody until the assay results are known.

Cases are known where the sample-bags have been enriched before the samples were put into them. It is therefore a wise precaution to keep the sample-bags in a lock-up sack until they are required. And even then it is advisable to turn each bag inside out and shake vigorously before use.

In the case of gold-mines, soft ore has been artificially enriched to a depth of a foot or more with a strong solution of chloride of gold.

Fraud has been practised on mine-examiners by stretches of rich ore having been skilfully built into the wall of a level at different intervals and at the working face, the joints being obscured by liberal splashes of mud. In the same way artificial outcrops have been prepared.

Dumps of ore have been *stacked* with rich ore on the sides and top surface. An imposture of this kind is at once disclosed by the process of trenching when procuring samples for assay.

Samples of gold-wash intended for examination by panning have been enriched, either before or during the washing, by the agency of gold-bearing tobacco-ash, pellets of clay, and gold-bearing finger-nails. The gold obtained from the panning of gold-wash or tailings should be examined under the microscope.

Bulk samples of ore have been *salted* during the process of treatment in the battery, either by the addition of gold or amalgam.

The examiner's samples may be unlawfully enriched at any stage from the breaking of the material in the mine to the assaying in the laboratory. Strong solutions of gold chloride have been injected into the bags with a syringe, and gold-dust added to the litharge and fluxes. Fraud is so easily practised in this stage that the examiner should either supply his own assay materials or test those placed at his disposal.

In these days of mine-valuation by systematic sampling, cases of *stacking* or *salting* of the ore in the mine are rare, and easily circumvented by the watchful examiner. But, besides covert acts intended to beguile, the examiner may be misled by the suppression of important developments, or by the blocking-up of workings where unfavourable results might be obtained.

On his part the mine-examiner must be careful not to assume an attitude of restraint and distrust towards those connected with the management. In the writer's experience, miners are as honest as most men ; and if they sometimes put the best side before you it is more from a feeling of loyalty to their employers than a deliberate desire to deceive. Probably not more than one in a hundred would wilfully mislead you, or use unlawful means to enrich your samples. But the hundredth man is generally a clever rogue, and needs close watching; and because of this one man you must take no risks, either in the mine or in the laboratory.

CHAPTER IX.

THE EXAMINATION AND VALUATION OF MINES.

CONTENTS: — Valuation of Metal Mines—Developed Mines and Going Concerns—Classification of Ore in a Mine—Valuation of Coal Areas—Valuation of Alluvial Ground.

THE payable ore in a vein or coal in a seam is manifestly a certain finite quantity; therefore the greatest coalfield and largest ore-deposit must eventually see a day of exhaustion. And if the total quantity of ore or coal and the annual output are known, the date of exhaustion is a matter of simple calculation.

A mining property blessed with a good constitution—that is, endowed with a considerable quantity of valuable ore, from the date of discovery to the point of exhaustion—naturally passes through the successive stages of infancy, youth, full-grown manhood, middle age, old age, and extinction.

Infancy is the discovery stage of mine existence; youth, the development stage; full grown, the payable going concern in the meridian of life; middle age, the going concern past the meridian; old age, the period of decadence and exhaustion. But all this is true only of the mine that survives the early stages of existence, and lives what may be termed a full and profitable life, leaving an honoured name behind.

Some mines give promise of their later vigour even in early infancy, and others that are weakly in infancy develop into a robust manhood. The greatest mortality takes place in infancy and youth. Scores of promising mineral discoveries are unable to survive the stage of development. They never become going concerns.

But sudden exhaustion is not an affection peculiar to the very old or the very young mine. There are many notable examples of vigorous mines coming to a sudden end through exhaustion of the ore reserves in a way not expected or provided for by the management.

The mine-examiner will, therefore, like the careful physician, have an eye open for possible constitutional defects that may cause sudden decadence in even the most vigorous. A mining property may be examined by a mining engineer for the following objects :—

(*a*) The purchase of mine by his principals.
(*b*) The purchase of shares or a share interest.
(*c*) Recommendations as to future development work.

The examination and valuation of a mine go hand-in-hand, but mine-examination is a very different thing from mine-valuation. Two independent engineers may examine the same property and collect the same data and information, but form quite different conclusions as to the prospective value of the property.

Experience and the *personal equation* count for much. The latter means that some naturally possess a sounder judgment and more discriminating mind than others, are better able to comprehend the meaning of facts, and hence more competent to form a true conception of a proposition presented to them.

The valuation of a mine is a prosaic, matter-of-fact problem requiring the exercise of the commercial faculty. Even in the most favourable circumstances the problem is not easy of solution, for the reason that some of the essential factors are often wanting, or merely represented by approximations. On the other hand, it must be clearly understood that mine valuation is something more than a purely mechanical operation. There is, besides, the subtle element that always distinguishes the skilful diagnosis of the internal condition and prospects of a patient made by the physician from certain external symptoms.

The essential factors of mine valuation may be summarised in two phrases, namely :—

(*a*) Adequate development.
(*b*) Systematic and conscientious sampling.

For purposes of examination, mining properties may be considered as belonging to one of three classes, as follows :—(1) Metal mines ; (2) Coal-mines ; (3) Alluvial mines.

Valuation of Metal Mines.—In the case of a property known to be metalliferous, or to contain some valuable mineral, the scope, and to some extent the method, of examination will be determined by the stage the mine has reached in its existence. The different stages in the life of a mine may be sub-divided as follows :—(1) Discovery stage ; (2) development stage ; (3) going-concern stage ; (4) decadent stage ; (5) abandoned.

Discovery Stage.—In this stage we assume—(*a*) That a vein or *ledge* has been located by the prospector, and a legal title obtained for the ground, forming what may be termed a *surface-show*; or (*b*) that the claim has been pegged out on *position* alone, no vein or seam of valuable mineral being exposed at the surface.

A Surface Show.—In this case the outcrop has probably been prospected by trenches and shallow shafts, sufficient to disclose the width, direction of strike, and dip of the deposit.

Having provided himself with the best topographical and geological maps obtainable, the mine-examiner will proceed with his examination, which will embrace a consideration of the following points:—

(1) The geological features.
(2) The physical features, particularly with reference to the subsequent working of the property, should the results warrant this course; note such points as the *backs* available—that is, if the vein can be worked water-free; but, if not, mention if sinking is likely to be wet or dry, mine-timber and water-power available, etc.
(3) Sample the outcrop at different points, noting the width of vein and peculiarities of structure.
(4) Mention the proximity, or absence, of valuable or worthless mines in the district.
(5) Make inquiries as to past history of the field, obtaining official statistics when possible.
(6) Gain a *personal* knowledge of the local peculiarities of the ore-deposits in the neighbouring mines, especially noting vein-structure, average width and value of ore, accessory minerals, country-rock, influence of different kinds of country, faults, intrusive dykes, methods of treatment, monthly output, mining costs, etc.

When once on the ground, the mine-examiner should make a point of acquiring all the general and particular information he can obtain for his future reference and guidance.

The results of the sampling and observations may be satisfactory, but the experienced mining engineer will be careful not to commit himself to a definite opinion as to the potential value of the property upon surface indications alone. The young engineer must not be afraid to report to his principals "that the development work is insufficient to enable me to form a definite opinion as to the probable value of the property." The experienced engineer finds no difficulty in doing so.

Bear in mind that the outcrops of silver, lead, zinc, and copper lodes are often *less* valuable than they are at some depth below the surface; while those of gold are in many cases *more* valuable.

Hence, with the former, the judgment must be guided more by mineralogical and geological considerations than by sampling.

If the outcrop values and general surroundings are satisfactory, the examiner will in most cases be warranted in recommending further development work being undertaken in order to open up the ground for a fuller examination. The mine-examiner, from his knowledge of the ground, will be able to indicate to his principals the nature, extent, and probable cost of such work.

In this case it will manifestly be to the interest of the intending purchasers to acquire a working option over the property for a period of six, nine, or twelve months, or, may be, if the work to be undertaken is considerable, two years.

The *deed of option* should be legally executed between the interested parties; clearly specify the term of purchase, and state which party is under obligation to pay rents, taxes, royalty, and comply with the labour regulations, etc., during the currency of the option.

The vendor may sometimes require an immediate cash payment of an agreed sum of money on the execution of the deed of option, such sum to be considered part of the purchase-money should the property be taken over; or he may covenant that a certain specified sum be spent in mine-development, either monthly or during the whole period of the option, as a guarantee that the work will be prosecuted with vigour.

It should be remembered, however, that the engineer for the purchaser is generally the best judge as to what sum should be spent in the development work necessary to enable him to form a reliable opinion of the value of the property. On the other hand, the chance of doing good business should not be lost by pursuing a niggardly policy with the vendors. Therefore, each case must be judged on its own merits.

So far we have assumed that the surface outcrops gave sufficient values to warrant further development being undertaken with a view of opening up the ground for a more critical examination. According to the configuration of the surface and position of the outcrops, the ore-vein will be prospected by levels driven "end on"—*i.e.* along the course of the ore-body, or by cross-cuts and levels therefrom, or by a shaft or shafts.

In selecting the sites for the aforesaid levels or shafts it is in most cases advisable to keep in mind the possibility of these works being utilised in the permanent working of the mine, should the results justify this course.

Again, the surface outcrops may be worthless and the prospects insufficient to warrant any expenditure on prospecting. On the other hand, the value of the property may be so obvious that the mine-examiner is justified in recommending the immediate purchase. In this case no prospecting should be undertaken by the examiner until a firm *option of purchase* has been acquired on bed-rock terms.

Undeveloped properties of such obvious value are rare, and hence extreme caution must be exercised by the examiner before recommending an immediate purchase. Ledges of silver-lead ore and gossans of pyritic ore-bodies have been discovered in situations that left little room for doubt as to their great value, even from surface sampling and examination; and the same has proved true of not a few valuable deposits of magnetite, specular iron, and manganese.

But even if the examiner have the immediate purchase of the property in his mind, he will seldom have much difficulty in obtaining the right (under an option of purchase) to spend a month or two in sampling and surveying preparatory to the completion of the purchase.

Pegged on Position.—This is generally an undeveloped property, often possessing no surface indications of valuable ore or mineral. It is, however, not on all-fours with the cases we have already discussed. In some cases position means everything; in others, nothing. For example, an area surrounded by working coal-mines, iron-mines, or oil-wells occurring in the same formation, in the absence of faults or igneous dykes, is an area already proved valuable by its juxtaposition to valuable mines. Or a claim pegged out on the strike of a lode that has proved to be payable up to the boundary is a potentially valuable property. Or a claim pegged out on the dip of a flat-lying lode, seam, or bed that has been proved to be valuable by the outcrop mines is a property, in the absence of great faults, igneous dykes, or a change of rock-formation, that may prove to be of great value.

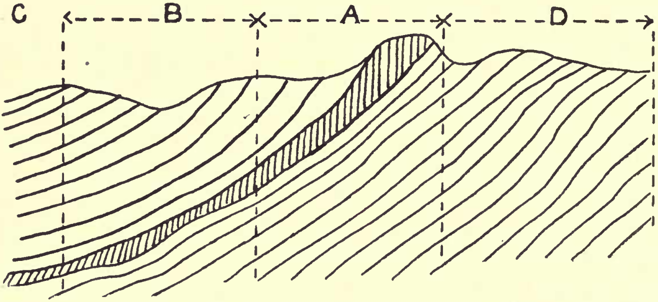

FIG. 74.—Section of Valuable Bedded Deposit.

In the above figure, A is an outcrop claim assumed to be valuable. Here B and C are claims pegged on position, and their potential value will depend upon the value and characteristics of the ore-body as disclosed by the mine working in the outcrop claim.

Manifestly the value of claims B and C can only be determined by shafts or by bore-holes. In the majority of cases boring will be resorted to as being cheaper, quicker, and affording the means of testing the deposit at a greater number of points.

Claim D has been pegged out on position. It is next to the out-crop claim, but being situated on the foot-wall side of the deposit its position counts for nothing.

In the case of steep lodes, claims pegged out on the dip-side may be worth little commercially, from the extreme depth at which mining operations would have to be conducted.

In this example claim B may be, for all practical purposes, of no more value than Claim C.

The valuation of *position* properties presents many difficulties. The mine-examiner will therefore need to make a critical examination of the ore-bodies in the adjoining mines, of the geological structure of the country, and a particular search for dykes, faults, or change of country.

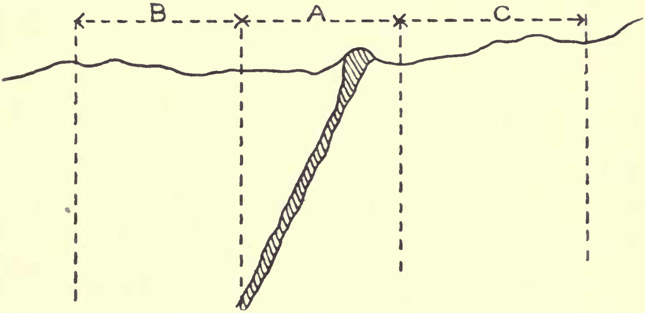

Fig. 75.—Section of Steep Lode.

The points which the examiner will bring under the notice of his principals are as follows :—

(1) Situation of claim and means of access.
(2) Area of claim and name of owners.
(3) Title—*i.e.* leasehold or freehold—with particulars of rents, royalties, labour conditions, etc.
(4) Geological features.
(5) Physical features, mentioning climate, forests, water-power, etc.

(6) Particulars of vein-outcrops, prospecting work done.
(7) Values obtained from sampling.
(8) Discussion of general surroundings.
(9) Opinion as to future prospects, and recommendations.

Three courses may be pursued, according to the circumstances —*i.e.* the property may be—

(*a*) Rejected.
(*b*) Secured on working option.
(*c*) Purchased.

If the engineer recommends that an option be secured, he should give full details of the character and extent of the proposed work, its probable cost, time required for the work, its effect when completed, and proposed method of supervision.

Developed Mines and Going Concerns.—The commercial valuation of a mining property in this stage is based upon the following considerations :—

(1) The quantity and value of *ore developed*, and quantity of *ore being developed.*
(2) The net profit per ton.
(3) The annual output to yield a net profit per cent. on a certain capitalisation.
(4) The probable life of mine.

The quantity of ore that might be expected to be opened up by further development work must not be lost sight of. But the quantity and value of such ore are unknown quantities, and the importance to be attached to them in calculating the mine value must in every case be determined by the character of the ore-body and the value of the ore already developed and won.

In all cases the fundamental basis of mine valuation is the *net profit in sight.*

Some veins are notoriously patchy, while others are equally consistent as metal-producers ; hence no safe rule can be laid down as to the prospective value of undeveloped ground. The local conditions must govern each case. It is, however, well for the engineer to remember that the ore-values of vein-deposits are more liable to sudden variation than those of bedded deposits.

As in the former cases, the mine-examiner will proceed to the ground equipped with the best topographical and geological maps obtainable ; also official reports and statistics, if any are available.

When once on the ground, the examiner will find it advantageous to pursue the following course of procedure, although it must be clearly understood that circumstances alter cases. The suggestions given here are general rather than special, and must be modified to suit the needs of each case :—

(*a*) Carefully examine the mine-plan. Get the mine manager to explain the general scope and extent of the underground workings.
(*b*) Examine the surface outcrops (if any), and note the geological and physical features.
(*c*) Examine the boundary-lines, and carefully note their position with respect to the dip and course of the vein ore-body or seam being worked in the mine.
(*d*) Note the relation of the underground workings to the surface boundaries.
(*e*) Have a look at the ore coming to the surface, also at the rock on the dump.
(*f*) Examine and make a note of the surface equipment, including mills and all metallurgical plant and appliances. When describing steam-engines, give the number and size of cylinders, maker's name, pressure of steam carried by boiler, etc.

The first day or two is spent in getting your bearings, and becoming acquainted with the manager and noting what manner of a man he is. A few days occupied on the surface in preliminary work is generally time well spent. Make a note of any facts presented or offered to you. Do not note opinions, and on your side be careful to offer none.

(*g*) Examine the underground workings accompanied by the mine manager or his deputy. According to the extent of the workings, it may take a day or two to do this.
(*h*) Again examine the mine plans. You will be able to follow them intelligently from the information you have gained underground.

You have now reached the critical stage in your examination. You have next to determine the condition of the mine; and among the questions that will naturally come into your mind will be the following :—

(1) Is this a young mine with a prosperous future ahead of it?
(2) Is this a young mine doomed to early exhaustion?
(3) Has this mine reached its maximum point of production?
(4) Is this an old mine approaching exhaustion?
(5) Is this an old mine with the *eyes picked out*?

The answer to these questions is to be found in the quantity and value of ore in sight. Do not forget that in a vigorous, well-managed mine the development work will be commonly two years ahead of the mill.

(*i*) Go underground with your *own assistant*, and sketch out your scheme of sampling.
(*j*) Sample the mine in a systematic manner. This may take a week or several weeks, according to the magnitude of the workings and size of ore-bodies. (The general principles of mine-sampling are described in the chapter treating of "Mine-sampling and Ore-valuation.")
(*k*) Complete your surface investigations. Get mine returns of output of ore and values extracted, or of mineral shipped or exported, mining and milling costs, etc. Carefully verify doubtful points.
(*l*) Before leaving the district make as complete an examination of the neighbouring mines as circumstances will permit, noting character of country, ore-bodies being worked, general characteristics of said ore, output, returns, methods of treatment, costs of mining and milling.

On no account allow yourself to be hurried in your examination. Take your own time. Cultivate a deliberate temperament. Base your estimates on facts, but be sure of your facts; and in your report be careful to differentiate between facts and opinions.

Your next care is the assay of your mine samples, and in this you must be guided by local considerations. If you are a skilful assayer, it is preferable for you to hire an assay office for a day or two, supply your own fluxes, crucibles, etc., and perform your own assays; or your assistant will probably be able to do so for you. In whatever way the work of assaying is done, it is imperative that the results must be accurate and reliable.

(*m*) Plot your assay values on tracings of mine-plans, and then consider the results.

The form of your report will depend upon your recommendations. Manifestly the property may be—

(1) Rejected.
(2) Secured on option.
(3) Purchased at once.

If, in your opinion, the property should be rejected, it will be unnecessary to furnish elaborate details concerning it. But if you recommend its purchase, it will devolve on you to supply information upon the following points: —

(1) The situation of property, and its relation to any valuable or worthless concerns in the vicinity.
(2) Means of access, with particulars of roads, railways, waterways, distances from centres of population, etc.
(3) The area, owners, and names of old claims (if any), included in the area; history, nature of title, labour obligations, etc.
(4) Physical features, including particulars of rivers, mountains, forests, rainfall, water-power available, etc.
(5) General geological structure: detail the rock-formations present, their probable age, relations, disposition, and distribution.
(6) Description of ore-bodies or mineral-deposits, with particulars as to their position with respect to boundaries of prospect; their dimensions, dip, strike, outcrop, etc.
(7) Description of old workings (if any).
(8) Character and extent of present workings.
(9) Quantity and value of daily output of ore.
(10) Quantity and value of ore in sight.
(11) Method of treatment of ore, or of disposal of mineral.
(12) The cost of mining and treatment.
(13) Probable net profit per ton, and per annum, on a specified annual output.
(14) Probable life of mine with a specified annual output.
(15) Description of present mining and metallurgical plant and appliances.
(16) Development work recommended (if any), and estimated cost.
(17) Details of additional plant, if any required.
(18) Recommendations as to management of property.
(19) Schedule of prevailing salaries and wages.
(20) Schedule of mine supplies required, and their cost delivered at the mine.
(21) Local and general rates, import and export duties, insurance, income and other taxes.
(22) Number of working-days in the year.
(23) Climatic conditions and prevailing sickness (if any).
(24) Mining legislation of country.
(25) Amount of working capital required to develop mine to a paying point.

Classification of Ore in a Mine.—*Ore in sight* and *ore developed* are terms used in mining to define bodies of ore contained in more or less rectangular blocks of *limited size* exposed by workings on all sides. They are only applied to ore that can be extracted and treated at a profit.

The phrase *ore in sight* is ambiguous, and may mean ore exposed on one, two, or more sides. It may thus be misleading, and should therefore be allowed to fall into disuse.

A simple and clearly defined classification of ore is as follows:—

(i) *Ore Developed.*—Blocks of ore exposed on four sides.
(ii) *Ore Partly Developed.*—Blocks of ore exposed on three or two sides.
(iii) *Ore Expected to be Developed.*—Blocks of ore that may be reasonably expected to exist beyond or below the last visible ore. Exposed on one side.

Philip Argall [1] considers that the three phrases *ore-developed*, *ore being developed*, and *ore expectant* should cover all the estimates a mining engineer is called upon to make.

In the case of a vein exposed by surface outcrops only, there is no ore in sight, notwithstanding that the values may be high.

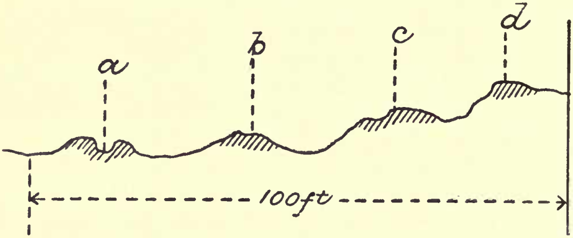

Fig. 76.—Longitudinal Section on Course of Lode.

Ore exposed in One Dimension.—In fig. 76 the letters *a*, *b*, *c*, and *d* represent prominent outcrops on the course of a lode. The hollows between these outcrops are assumed to be obscured by overburden. A number of samples selected at each outcrop showed the presence of valuable ore. Manifestly any estimate of the quantity of payable ore would be mere guesswork.

There is nothing to show that the payable ore is continuous between the different outcrops It may or may not be so. Again, the payable ore at the different outcrops may be mere local patches, or the truncated remains of a pay-shoot that may have been of considerable dimensions prior to the later sculpturing of the country.

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[1] T. A. Rickard, *The Sampling and Estimation of Ore in a Mine*, p. 80, New York, 1904.

In the above example we have the proof of the *first principle*, in accordance with which *an ore-body exposed in one dimension* affords no basis for the estimation *ore in sight.*

Ore exposed in Two Dimensions.—We will now assume that surface excavations have proved the continuance of the pay-shoot from points *a* to *c*, fig. 77, and that a shaft has been sunk on the vein at point *b* to a depth of 60 feet.

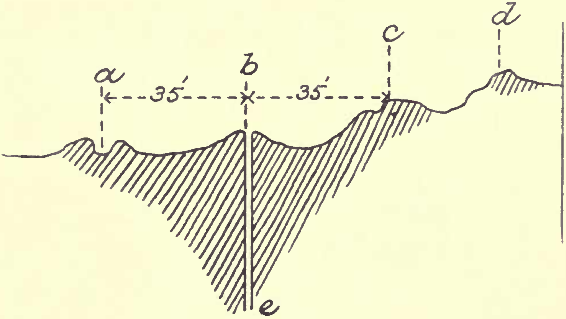

FIG. 77.—Longitudinal Section of Lode.

The shaft sunk at *b* exposes two sides or dimensions of the triangles of ore *a b e* and *c b e* for a thickness equal to the width of the breast of ore exposed in the shaft.

Let *a b* = 35 ft., *b c* = 35 ft., and *b e* = 60 ft., and the mean width or thickness of pay-ore = 4 ft. Assuming that the payable values continued to the bottom of the shaft, we have two triangles of ore partly developed.

From the above we get the mining engineer's second principle, *That an ore-body exposed in two dimensions gives a triangle of ore only partly developed.*

Ore exposed on Four Sides.—In this example a level has been driven on the course of the vein, and a rise put up from point *f* to the surface, and another rise from *z* to *n*. The dotted line *s n m* shows the limits of the pay-shoot on the west side of the shaft. The *ore developed* now includes the rectangular block *b e f c*. The irregular block *b s m e* is exposed on three sides, and therefore contains ore not fully developed. The reliance to be placed upon estimates of value in this block will depend upon the characteristics of the ore-body and local conditions. The capacity of these ore-bodies can easily be calculated for any given width.

From the above we get the third principle, *That an ore-body exposed in four dimensions gives a rectangular area of ore-developed of a known approximate mean width and value.*

It is manifest that three dimensions do not fully expose a rectangular body of ore. If in the above example we take sides *b e*, *e f*, and *f c* as the known dimensions, then the value of the triangle *b k c* is an unknown quantity. Again, if *e b*, *b c*, and *c f* are the known dimensions, then the triangle of ore *e k f* is unknown.

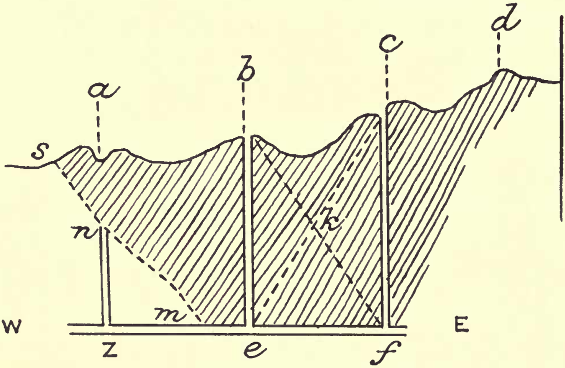

FIG. 78.—Longitudinal Section of Lode.

In working mines, with the development well in advance of the mill, the levels and rises by means of which the ore is cut up into rectangular blocks for stoping afford four dimensions or sides for examination and sampling.

Only in exceptional cases should the length of a block exceed twice the height. The smaller the blocks the more trustworthy will be the estimates of *ore developed.*

Estimation of Tonnage.—This is found by dividing the number of cubic feet of solid ore contained in the block by the number of cubic feet of solid ore in a ton. The number of cubic feet in a ton of ore depends on the specific gravity of the ore, and varies from 12 to 15 cubic feet for a ton of 2000 lbs.

In measuring up ground which is fully developed allowance must be made for faults, dykes, probable *horses* of rock and pillars of ore that will never be taken out. A deduction of 10 per cent. will be sufficient in most cases; but obviously no empirical rule can be laid down. The character of the ore-body and containing rock, and local experience, will afford the safest guides to follow.

Probable Ore Reserves.—In many cases the mine-examiner may be justified in assuming that the payable ore extends above or below the working faces or open ground. In this matter he must exercise great caution. His only guide is the general metalliferous character of the ore already won. The pay-shoot may extend a hundred, or only a few, feet beyond the face, or below the level. Strong pay-shoots have been known to cut out in the height of a stope or two; and for this reason the examiner must clearly discriminate between *ore developed* and *probable ore*.

Valuation of Coal Areas.—In no department of mining is a knowledge of field geology so requisite as in the examination and valuation of a coal-bearing area. A seam of coal is a member of a geological formation, and therefore the determination of its extent is a geological problem.

The examiner should provide himself with the best topographical and geological maps obtainable, and any official reports dealing with the geology of the district.

When the ground is reached, he will first make himself familiar with the different members of the coal-bearing series, noting particularly their physical character, thickness, fossil contents, the horizon in which the coal seam or seams occur, and the character of roof and floor of coal.

A visit to the neighbouring coal-mines, if any exist, will enable the examiner to obtain much valuable and necessary information respecting the above.

The next point is to determine the relationship of the coal-measures to the underlying and overlying formations. This is most readily determined by running cross-sections across the line of strike at different intervals, carefully noting distances and elevations of prominent outcrops and changes of rock-formation.

Having made himself familiar with the general geological structure of the district, and more particularly with the members of the coal-measures, the examiner will proceed to plot the boundaries of the coal-bearing rocks on his topographical map, whereon he will also mark the direction of strike, dip, angle of dip or inclination of beds, thickness of seams, faults, dykes, coal-outcrop, etc.

A cross-section of each outcrop is recorded in the field-book, with remarks as to thickness of seam, character of coal, fireclays, ironstone, associated rocks, etc.

If the angle of inclination of the coal-measures and contours of the ground preclude the possibility of coal-outcrops existing in the area under examination, the examiner will have to base his opinion as to the coal-bearing prospects of the ground solely upon geological considerations. In this case his examination of the geological structure of the field and of the neighbouring coal-mines will be more exact and critical than if numerous outcrops existed. And in many cases he will be warranted in recommending boring at selected points, in order to determine the thickness and depth of the coal.

In the majority of cases the examiner's report will deal with the following points :—

(1) Situation and means of access.
(2) Area, title, owners, rents or royalty, etc.
(3) Geological structure, illustrated with cross-sections.
(4) Physical features, with reference to forests, rainfall, water-powers, etc.
(5) The area of coalfield. (This should be shown on a coloured plan.)
(6) Thickness of seams, and presence of stone-partings.
(7) Existence of faults and dykes.
(8) Probable tonnage of coal ; presence of fireclay and ironstone.
(9) Quality of coal. Is it hard and strong, or soft and friable? Give analyses of coal : state whether it is useful for steam, household, gas, smelting, etc., purposes. Discuss proportion of sulphur present, water, ash, etc.
(10) State if any portion of the field lies so as to be water-free, and, if so, what area.
(11) Give probable cost of mine-development.
(12) Cost of surface equipment.
(13) State probable cost of production.
(14) State situation of market for coal, access and probable cost of transport of same.
(15) Discuss extent of market, probable competition, etc.
(16) State the probable net profit per ton.

In an area in which the quantity of coal is deduced from surface outcrops and a few boreholes it is a needless refinement to attempt to calculate the quantity of coal with mathematical exactness.

Having determined the approximate area and thickness of coal, and made due allowance for broken coal along outcrop, faults, and dykes, the quantity of coal that can be extracted may be calculated on the following basis :—

	Tons per Acre.
For every foot of brown coal, . .	1000
,, pitch coal, . .	1100
,, bituminous coal, .	1200
,, cannel coal, . .	1300
,, anthracite, . .	1500

Seams of coal and beds of shale are sampled in the same way as a vein—that is, by cutting a narrow groove from roof to floor at right angles to the plane of the dip. Surface outcrops should be dressed down with a pick before the sample is broken, as outcrop coal is often waterlogged ; and sometimes the cracks are filled with fine sediment or sand carried over the exposure by running water or rain.

VALUATION OF ALLUVIAL GROUND.

The valuation of alluvial or placer deposits, either for dredging or hydraulic sluicing, is affected by determining the amount of gold contained in a measured quantity of material obtained from shafts or boreholes placed at regular intervals in the area under consideration.

The Work of Sampling.—First survey the block of ground, and plot it on paper to a large scale—say, 2 chains to the inch for areas between 50 and 100 acres, and 1 chain to the inch for areas under 50 acres.

Divide the ground on the plan into blocks of 1 to 5 or 6 acres. The shape of the blocks will depend on the surface contours, the direction of the drainage, and the probable direction of the gold-leads.

In some cases the ground is a long narrow strip situated on one or both sides of a river; in others, terrace lands in a valley, which are in many cases intersected by lateral streams.

Make a mark in the centre of each block, and then number the blocks in consecutive order. Proceed to the ground and put a stake or flag in the centre of each block. These stakes mark the sites of the sampling holes.

The depth of gravel may vary from nothing to 40 feet, or more in very deep ground.

Where the ground is dry and not deep it is customary to sink holes or shafts at the selected points. The *whole* of the material excavated from the hole is carefully measured in a box of known capacity, washed by cradling, the gold contents weighed, and the results recorded.

The record of each hole embraces information on the following points:—

(1) Depth of ground.
(2) Character of bottom—that is, whether slate or *false* bottom.
(3) Character of gravels (note particularly if beds of clay, large boulders, or drift timber exist in ground).
(4) Quantity of material excavated in cubic yards, plus 20 per cent. (all the boulders, both small and great, must be included in the measurement).
(5) Quantity of gold obtained.
(6) Quantity of gold per cubic yard.

In ground where the sinking of holes would be impeded to any considerable extent by water, it is usual to put down 5-inch or 6-inch bore-holes at the selected points. The holes are lined with tubing, and the material extracted by the sand pump, collected in a wooden trough, washed, and the gold contents weighed.

Record the depth of the hole, and calculate the cubic contents from the outside diameter of the pipe, plus 20 per cent. The excess is added because experience has shown that the gold values calculated from the displacement of the pipe alone are always higher than the actual returns. This is, no doubt, largely due to the circumstance that a higher extraction or saving of the gold is effected in the sampling tests than in actual practice.

Wrong Methods of Sampling.—The method of selecting the test samples from open faces or from the sides or floor of small streams has often led to erroneous conclusions. In these places the gold is generally more or less concentrated, thus rendering it impossible for the examiner to form an approximate estimate of the average value of the gravels.

Pannings taken from the toe of gravel faces and from water-courses cut through the gravels are interesting, but inferences drawn from the gold obtained are usually very misleading. Furthermore, it must not be inferred that a placer claim which returns good wages to a small party of working mates will necessarily pay dividends to a company working on a large scale.

Working on a small scale the miners are always on the track of the gold. If the *lead* is lost, the fact is known at once; but working on a large scale, where the shifting of quantity is an important factor in order to insure adequate returns for the capital invested, rich and poor gravels alike are moved, thereby reducing the general average.

Calculating the Average Value.—The average value per cubic yard is found by multiplying the number of grains of gold per cubic yard found in each hole by the depth of the hole in feet, and dividing the sum of these products by the sum of the depth in feet, as follows:—

No.	Depth of Hole in Feet.	Grains of Gold per Cubic Yard.	Products.
1	14	3	42
2	15	4	60
3	18	2·5	45
4	16	3·5	56
5	13	3	39
6	14	5	70
7	12	2·5	30
8	10	9·5	90
9	8	6	48
10	14	4	56
...	134	...	536

The sum of the products is 536 and of the depth 134, therefore the average value is $\frac{536}{134} = 4$ grains of gold per cubic yard.

The average depth is $\frac{134}{10} = 13{\cdot}4$ feet.

The area of the ground and the mean depth being known, the total cubic content is easily determined; but ample allowances must be made for the possible inequalities of the bottom, etc.

Dredging for gold in river-channels, river-terraces, lagoons, etc., and the working of placer-deposits by hydraulic sluicing and elevating, are conducted on a large scale in New Zealand and California.

At the end of 1903 there were in the South Island of New Zealand[1] 272 dredges, of which over 200 were working, the balance being under repairs, or removed to other ground, standing idle, wrecked, etc.

At the end of the same year there were 2932 water-races, having a total length of 6852 miles, and carrying 12,285 cubic feet of water per second; and 2346 tail-races in connection with placer mining.[2]

The experience of gold-dredging and hydraulicking in New Zealand has proved conclusively that where the ground has been systematically sampled by an experienced engineer practically no failures are known.

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[1] Report of Department of Mines, New Zealand, 1904, p. 12.

[2] *Loc. cit.*, p. 188.

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