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GEOLOGY

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GEOLOGY

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"ROMANCE OF REALITY" SERIES

GEOLOGY

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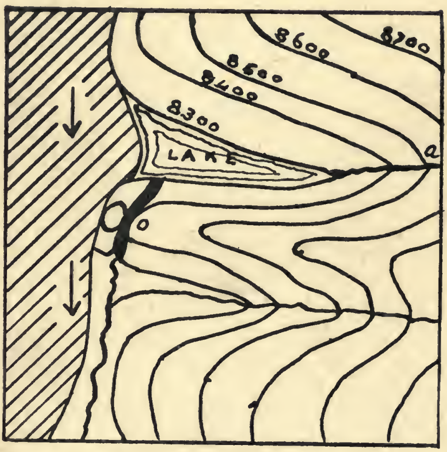

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GEOLOGY

PART I.—INTRODUCTORY

CHAPTER I

THE EARTH AND ITS EARLY HISTORY

It is very strange, but nevertheless true, that most people are content to go on living in this world without attempting to find out anything about the world itself. They have been told that it is round, that it moves round the Sun once in a year, and that it turns on its axis once in twenty-four hours. They also know that it is made up more or less of hard substances which are called rocks. Beyond this they do not care to go in the paths of knowledge unless their particular calling is directly connected with some mineral industry.

The excuse frequently brought forward to account for this want of interest is that their energies are so taken up with business of one sort or another that they have no leisure for the study of a subject which in their opinion is very dry and uninteresting. That it is uninteresting it is hoped will be disproved in the present volume, and even if the writer admitted its uselessness, which is far from being the case, he would ask how many other methods of enjoyment and recreation are without their direct utility.

The reading of well-chosen fiction, it is true, tends to widen the views, but after all it is but the opinions of men and women, based in some few instances on actual experiences. It deals principally with the actions and thoughts of men and women as they are affected by the emotions such as religion and love, or with questions of ethics, sociology, or politics.

By confining ourselves to this type of literature we are apt to become narrow in our views and to depend upon others for our opinions of this and that, and only too often we confine our reading to a favourite group of authors, and thus do not even get a very great variety of opinions.

Many of our social customs and some of our beliefs have arisen as the direct results of the natural forces working around us, and these are the customs and beliefs which will stay with us from generation to generation. Others which have been raised, it may be to meet and attempt to overcome some past or present difficulty or social evil, will, in so far as they are contrary to the great fundamental processes of Nature, inevitably perish. It is then desirable that we should all have some knowledge of the forces about us, that we may be able to form conceptions of our own, and not be obliged to follow like a flock of sheep the bell-wether of other people's opinions.

We speak of the fundamental processes of Nature and of natural laws, but how few of us really trouble ourselves about them. We all agree that it is for the good of the human race that we should possess some knowledge of and utilize these forces for our comfort and well-being, but how many of us take any pains to study them, so that we may fit ourselves to discover new principles and turn them to novel uses for the benefit of ourselves and our neighbours.

Though it is, or should be, the object of every worker in science to add something new to his subject, and on that account to have his chief interest in the present and future states of his study and in its practical applications to everyday needs, it is sometimes entertaining and even profitable to study the ideas of past workers in our field, so that we may beware of the modes of thought which led them into error, avoid the dogmas and superstitions which sometimes caused them to halt on the verge of great discoveries and to reject great principles since proved to be true, and to be stimulated by a contemplation of perseverance and singleness of purpose of some of the great masters, under the most disadvantageous circumstances, to a better use of the great opportunities which they have handed down to us.

From very early times speculations with regard to the origin of the Earth and of the features which vary its surface have been brought forward and discussed, though Geology as an exact science is one of the youngest of the sisterhood. Indeed, a little over one hundred years ago this branch of science had no accepted name.

The earliest forerunner of the science of Geology was what is generally known as cosmogony, a term used to indicate the wild and often baseless speculations of dogmatists with regard to the origin of the world and of the Universe as well as the sober and reasoned theories of more scientific workers.

As a natural consequence of the facts that in early times education was almost wholly confined to priests or the members of religious orders, and that the laity were usually unable to read or write, early cosmogony was always almost inextricably mingled with religion, and only too often reason was clouded and overshadowed by superstition.

Though they differ in many particulars and details, there is a strange similarity between the cosmogony of the early Indian and Egyptian schools of thought. They agree in ascribing the creation of the Universe, which to them was centred about the world and the human race, to an omnipotent being who possessed many of the drawbacks and inabilities of humanity, amongst others the need of rest and even of sleep.

Some seem to have attributed the creation of the actual matter of the Universe to this being, while others considered that the "inert matter" was an original first cause, and that it was caused to take definite form and to go through certain cycles of activity by the compelling will of the creator.

Amongst the ancient inhabitants of India certain sacred songs and poems had been passed on from mouth to mouth during many generations, and were first brought together into a connected form about thirteen centuries before the birth of Christ.

From the different views expressed in these vedas they would appear to have originated at different periods characterized by ideas of varying degrees of advancement, and therefore to be considerably more ancient than the Ordinances of Manu, the holy book of the Brahmans, of which they form the basis.

In these ancient writings we find the belief that the alternate periods of waking and of sleep of the creator Brahma, the compelling will or force, were connected with great upheavals of Nature.

"Thus this immutable power, by waking and sleeping alternately, revivifies and destroys alternately, in eternal succession, this whole assemblage of locomotive and immovable creatures."

It would appear from the Vedas that their composers knew of the long polar night and connected it with the southerly course of the Sun during the northern winter.

They were Aryans, and probably came into India from beyond the Himalayas, and had thus been in touch with the far north.

At a later stage there appears to have sprung up the idea that Brahma, the creator, having completed his labours, had lost further interest in the Universe and its inhabitants, and the alternate destructions and revivifications were attributed to Siva, the destroyer, and Vishnu, the preserver.

Belief in supernatural intervention has permeated in the past, and indeed still enters into many writings and theories concerning the Earth, and though modern Geology treats only of those founded, or supposed to be founded, on a natural basis, its influence on the history of the science has been so profound that it cannot be neglected.

Amongst the ancient Greeks were many men who studied Nature from an observational standpoint, and their views were often much discussed both by themselves and by others. Only too frequently then, as now, however, the victory in these disputations was to the man of many words rather than to him of sound observation and deduction.

Accordingly we find that while some of the Greek writers founded their views on observation, perhaps slightly tinted by mythical ideas, others simply followed the older ideas without troubling to seek observational confirmation of them.

As examples from this period we may take Pythagoras (580 B.C.) and Aristotle (384–322 B.C.).

The former believed that changes had taken place in the relative positions of land and sea, that the valleys were the result of the denudation of the solid land by the agencies of streams and rivers, and many other things which are now accepted as geological facts.

"Nothing perishes in the world, but things change their form. To be born means simply that a thing begins to be something different from what it was before, and dying is ceasing to be the same thing."

Here we have a foreshadowing of the modern doctrine of the indestructibility of matter.

Aristotle, who by his researches in natural history and his profound reasoning powers was venerated throughout the Middle Ages as the creator of all the sciences, seems on the other hand to have followed the older myths as regards cosmogony, and to have believed in a succession of inundations alternated with conflagrations.

After the introduction of Christianity a long period elapsed during which little advance was made in the direction of obtaining further facts relating to the origin of the Universe. The Hebrew version of the creation, not essentially different from, though perhaps more detailed than, other Eastern traditions, was universally accepted, and any attempts on the part of thinkers to throw doubt on the literal truth of this account were severely discouraged on the grounds that they were subversive of religion and morality.

Such was the prejudice against what were considered advanced views on matters of this kind that physical violence was often resorted to for their suppression, and many are the stories in medieval literature of the cruelties inflicted on men, and women too, whose only fault was a wish to use the brain and develop the powers of reason with which they were endowed, under the plea that they were practising the "black art."

Any departure from orthodoxy in the smallest particular, if allowed to become general, would undoubtedly weaken the hold of the priesthood upon the people, which, though in the then state of their education, would doubtless have been to some extent detrimental to the well-being of the community at large, would have fallen still more heavily on the priests themselves, and was therefore discouraged by the princes of the church.

It had long been known that there occurred in the rocks objects resembling the shells of animals which inhabit the waters of the sea, and the sixteenth century saw the commencement of a great controversy as to their nature and origin.

We are now so familiar with the idea that these fossils are the remains of animals which once peopled the waters and were the ancestors of forms now living that many of the ideas expressed at that time seem to us absurd.

We must remember, however, how many of the possibilities of our modern civilization, the instruments which are in daily use, such as telephone and telegraph, also our railways, our steamships, power-looms, submarines, and flying machines, would have appeared impossible, if not foolish, to our countrymen of four or five generations ago, and then we may be able to appreciate the difficulties which the men of the sixteenth and seventeenth centuries had in accepting ideas which, in the absence of a general knowledge of geological facts such as we now possess, would be as strange to them as that of wireless telegraphy to a person who had never heard of electricity.

A few writers believed that the fossils were the relics of animals and plants that had in past ages peopled the surface of the Earth, but this view did not meet with very general acceptance. Others preferred to consider them as the creatures yet unborn which would one day come to life and people the globe—a belief which those who have visited the fossil galleries of one of our great museums and seen the remains of the great fossil reptiles will be glad to learn is no longer held by those best competent to judge.

Another argument whose worthlessness will, I think, be at once apparent, but which nevertheless at the time it was brought forward received some support, was that fossils had nothing whatever to do with life, past, present, or future, but that Nature, always working symmetrically, having produced certain forms in the animate world, could not avoid the formation of similar shapes in the inanimate.

Much information had been accumulated as to the nature of fossils and their mode of occurrence, and it was slowly forced upon the observers of the period that the fossils must be accepted as the remains of the life of the past.

At first it was supposed that all the fossils might be of the same age, and their occurrence on mountain-tops and other unlikely spots be accounted for by a universal deluge, a view which was eagerly adopted by the theologians who at once set about the linking up of this great flood with the Noachian deluge.

It was realized, however, by those who had first-hand knowledge of the fossils and of the rocks in which they were found, that the enormous masses of the latter could not have been accumulated during any such brief episode of the Earth's history, even if it could be shown on geological evidence to have occurred.

Many writers set about proving that such a universal deluge was possible, apparently under the impression that to demonstrate the possibility of a thing was equivalent to proving that it had really occurred.

To give some idea of the very varied opinions which were held on this point, it will be sufficient to mention that while one writer believed that the Earth had originally been covered by a universal ocean which had been absorbed into the interior by the cracking of the crust, another stated that at first the waters were inside, and when the shell was cracked by the heat of the Sun they rushed out and so produced the deluge.

Realizing that the rocks containing the remains of living creatures represented a long period of time, R. Hooke (1668) believed that one day it might be possible, with a fuller knowledge of the fossils, to use them in the building up of a geological time-scale—a belief that has been justified to a far greater extent than was ever dreamed of by its originator.

Leibnitz and Buffon, the most celebrated of the cosmogonists, born in 1646 and 1707 respectively, though holding opposed views as to the means by which the waters had advanced upon and retreated from the land, were at one in their wish to advance observational methods.

Leibnitz believed that the Earth was at first a sphere of molten liquid which by its cooling and consolidation had become rough in surface, the protrusions giving rise to our mountain chains. The original crust constituted the "primary rocks," and upon these, with further loss of heat, the surrounding vapours condensed as a universal ocean.

He it was who promulgated the idea that the waters were drawn off into the interior of the now cold and solid Earth, so that stage by stage the land appeared above their surface.

The disturbances of the waters produced by these changes of level he believed to have produced the sedimentary rocks, and that, after several repetitions of this action, a balance had been arrived at, under the influence of which the present state of affairs was preserved.

Buffon possessed the power of broad generalization in a most marked degree, and his writings are most fascinating, not only on that account, but also because of the lucidity and eloquence of his style.

He felt that the history of the Earth must be definitely connected with that of the whole Solar System. He believed that the Planets, including the Earth, had been detached from the Sun by the collision of that body with a comet, and though we can no longer, from our knowledge of the nature of comets, believe such a collision sufficient for the purpose, we cannot but admire the man who first attempted to explain the Solar System on mechanical principles.

When he came to the question of fossils, however, he was in difficulties inasmuch as he had no conception of a force capable of raising the sea-floor above the waters, and so he arrived independently at the same conclusion as Leibnitz—that the waters had passed into the interior.

He divided the Earth's history into seven epochs during which the mass torn from the Sun first assumed the spheroidal form and then, having solidified, gradually passed from stage to stage until the present conditions came into existence.

The Faculty of Theology of the Sorbonne compelled Buffon to publish a retraction of his Theory of the Earth, but once men have been set thinking on such lines it is futile to attempt to restrain them; progress may be hindered, but the fruit will ripen in due time.

Important work was being carried on about the same period by Jean Étienne Guettard, who was born near Paris in 1715 and who in his youth worked with his grandfather, an apothecary. His interest in natural history, which was early manifested, caused his grandfather to allow him to become a doctor of medicine, and he afterwards travelled extensively as a member of the suite of the Duke of Orleans.

His first study was botany, which he pursued both in the country near his home and also at the Jardin des Plantes, after which he became interested in mineralogy and, through its influence, in the wider problems of Geology.

He was the first to prepare a geological map, that is to say, a map on which the distribution of the various kinds of rocks and minerals is indicated.

Guettard also added largely to the knowledge of fossils, particularly of fossil sponges and corals, and it is probably largely due to his labours that the great palæontological school of France came into being, and that his countrymen are still pre-eminent in that domain of science.

At this period the science of mineralogy was much in vogue. Minerals had long been studied from an economic standpoint, and the term mineralogy was then taken to include the study of rocks and their contents.

That the Earth's past history might be preserved in the rocks and their fossils was an idea which appears to have dawned upon Buffon, but was more fully realized by Guettard, though he does not appear to have made any definite observations in support of the view.

Guettard had observed rocks which he believed to be of volcanic origin in central France, far remote from any active volcano, and from this discovery there eventually resulted that greatest and most bitter of all geological controversies regarding the origin of basalt.

Nicholas Demarest, who was born in very poor circumstances at a little town near Brienne, was destined to play an important part in this great controversy.

Such was the poverty of his parents that at the age of fifteen he could hardly read, but on the death of his father he was educated by one of the religious orders first at Troyes and afterwards at Paris.

For a period of ten years he earned sufficient for a bare livelihood by private teaching in geometry and physics, but at the end of that time, when he was twenty-eight years of age, he came into prominence by winning a prize for an essay on the question as to whether England and France had ever been joined together.

He reached his conclusion that the two countries had been so joined by a careful examination of facts, and would have nothing to do with speculation. He confirmed observations made by Guettard that the opposing cliffs of the two countries were of similar materials, and further called attention to the former existence in England of certain wild animals which would have been quite incapable of swimming the Channel.

This essay was the means of bringing Demarest into touch with the great men of his day, and he was eventually employed by the French Government to report upon the state of the various industries of the country—a duty which necessitated much travelling from place to place and consequently provided many opportunities for geological research.

He held his post of Inspector General of the Manufactures of France until the Revolution, when he was imprisoned and barely escaped with his life.

When order was once more restored he was again employed by the Government in his former capacity.

Often he would tramp about from place to place, carrying some cheese for his sustenance and sleeping in the huts of the herdsmen so that he might study the rocks of the country, and it was during his wanderings in Auvergne that he was struck by the strange black columnar basalts of that region.

Basalts had been known and described in many parts of Germany and at the Giants' Causeway in Ireland, but up to the time of Demarest, basalt and lava had not been connected. In Auvergne, on the edge of the plateau of Prudelle, he found a part of an ancient lava-stream isolated by denudation and showing columnar structure, and afterwards observed the same structure in undoubted lava flows definitely connected with the Puys, as the extinct craters of that district are called.

He was thus led to believe that basalt belonged to the class of volcanic products. "I draw from this recognized resemblance, and the facts that establish it, a deduction which appears justified by the strength of the analogy—namely, that in the Giants' Causeway, and in all the prismatic masses which present themselves along the cliffs of the Irish coast, in short, even among the truncated summits of the interior, we see the operations of one or more volcanoes which are extinct, like those of Auvergne. Further, I am fully persuaded that in general these groups of polygonal columns are an infallible proof of an old volcano, wherever the stone composing them has a compact texture, spangled with brilliant points, and a black or grey tint."

It was fully two years after his memorable visit to Auvergne that Demarest communicated his results to the Academy of Sciences at Paris, and not wishing to be precipitate in the publication of his views, it was by his wish that the paper did not appear in the *Memoirs* *of the Academy* until 1774, eleven years after the original discovery.

Abraham Gottlob Werner (1749–1817) was a man of vast influence owing to his power of impressing his opinions upon his hearers. He was an enthusiastic teacher and drew men from all countries to the Mining Academy at Freiberg, where he was appointed Inspector and Teacher of Mining and Mineralogy in his twenty-fifth year—a position which he held for forty years.

He had from his earliest childhood been brought up amongst minerals and things pertaining to them. His father was inspector of Count Solms' foundry at Wehrau in Upper Lusatia, and the boy Werner was allowed to see occasionally, as a reward for industry, a small collection of "ores and spars" which his father had gathered together.

In spite of his enthusiasm for study he stands out in later life as a dogmatic theorist "intolerant of opinions different from his own, training his pupils in an artificial and erroneous system, and sending them out into the world not patiently to investigate Nature, but to apply everywhere the uncouth terminology and hypothetical principles which he had taught them."

He was directly the cause of the great basalt controversy, though he appears to have taken little part in it himself.

One of Werner's fundamental doctrines was the existence of universal formations, and he taught that these formations were to be recognized all the world over in the same order and with the same characters, but, strange to say, at the time when he brought out his system he had never travelled beyond Saxony or its immediate neighbourhood.

He believed that the Earth had once been surrounded by an ocean which overtopped the mountains, and that the solid rocks of his "formations" were deposited in a definite order as chemical precipitates from its waters. Of these precipitates basalt was one, and thus arose the Wernerian School of "Neptunists" as they were called in contradistinction to the Vulcanists, who supported the view that basalt was a product of volcanic activity.

Werner adopted the idea that volcanoes were due to the combustion of subterranean beds of coal, and that they were mere accidental occurrences of recent date.

It will be seen that the great Werner, though he prided himself upon having nothing to do with theories, was himself promulgating one of the wildest theories and the least supported by fact that has appeared in the pages of geological literature.

The great controversy, however, served to awaken in men's minds the need for further knowledge, and brought home to workers more closely than ever before the necessity for careful personal observation and for geological travel.

Mention is made in Chapter IV. of the work of James Hutton and of William Smith, who, more than any others, have contributed to the groundwork of modern Geology, and whose work has finally dissipated the older type of speculations regarding the Earth and its origin.

The writer is largely indebted to a work of Sir

Archibald Geikie[1] for many of the foregoing historical details given, and strongly recommends its perusal to those of his readers who are interested in this phase of the subject.

In studying those branches of knowledge which we bring together under the heading of natural science, many mistakes have been made through confining the attention too closely to some little point, which was the exact subject of experiment at the moment, and failing to connect it with its larger and more important surroundings.

In this way countless theories have been formed which, though they reasonably account for the one little point, fail utterly when applied to other similar points, and have therefore to be given up.

Geologists, amongst others, are by no means free from blame in this respect, though the wide scope of their subject should tend to produce a wider range of thought than is the case with some of the sciences often described as more "exact."

There is, for example, a great and fundamental question as to the mode of origin of the Earth, which has received, until recently, but little attention on the part of Geologists, who have, for the most part, cheerfully left it in the hands of Astronomers and Physicists, to whose domain it perhaps more properly belongs.

The work of the Geologist is to study the processes at work on the Earth's surface and those in progress in its interior so as to enable him to understand not only what changes are now going on, but also those which

[1] *The Founders of Geology*, by Sir Archibald Geikie, F.R.S. London: Macmillan & Co. Ld., 1897.

have been active in the past and have slowly brought our world into the condition in which we now find it.

As we shall see later, a knowledge of the mode of origin of the Earth is necessary for many of these ends, and we shall therefore first turn our attention to the study of the Earth as a whole and its relations to the other bodies in its neighbourhood.

When we wish to indicate the whole assemblage of the heavenly bodies, and the vast space which lies around and between them, we use the term Universe. The Universe is so vast that we can form but a vague conception of its dimensions—in fact, every increase in the power of our telescopes, or improvement in the photographic apparatus which we use in connection with them, makes new additions to our knowledge and extends the boundaries of the visible Universe.

With the actual dimensions of the Universe, even if these were ascertainable, we have little to do, suffice it to say that light, which travels 186,000 miles in one second, takes rather more than three years to travel from α Centauri, the nearest star, to the Earth. We now see the "Dog Star," Sirius, by the light which left it seventeen years ago, and the light now reaching us from the Pole Star started nearly half a century ago. Other stars are perhaps a hundred or even a thousand times more distant.

There are two main classes of bodies visible through our telescopes—stars and nebulæ.

The stars are in many cases similar to the Sun; they shine by their own light, and for anything we know to the contrary, may be attended by families of planets.

There is an instrument called the spectroscope which is used to break up or analyse light, and by its means we can compare the quality of light from one source with that from another. When looking through a spectroscope we see a band of colour, red, orange, yellow, green, blue, and violet, as in the case of the rainbow. Now, if the source of the light is the Sun, there will be a number of black lines running across the band of light, and these lines have been proved to belong to the spectra of different metals and gases, such as Iron, Sodium, Hydrogen, and Helium, so that we know that these substances are present in the Sun.

In the same manner, by examining the light of a star, we can find out a number of the elements of which the body is made up, and many stars have been shown to have a similar composition to the Sun.

The Sun is therefore but one of the countless thousands of stars which, separated from one another by hundreds, if not thousands, of light-years,[1] go to make up the visible Universe.

The second class of bodies referred to above, the nebulæ, are, as their name suggests, cloud-like masses, and they are faintly luminous. They cannot be seen by the unassisted vision, but when viewed through a telescope are found to be of two main classes, one having a more or less spiral arrangement, and the other being quite irregular in form.

These bodies are of great interest to us, as it is almost certain that the planets, including, of course, the

[1] A "light year" is the distance which light travels in a year and is the unit employed for measuring stellar distances. It is $186,000 \times 60 \times 60 \times 24 \times 365 = 5,865,696,000,000$ miles.

Earth, and possibly the Sun, have been slowly evolved from a parent nebula.

Let us now ascertain the position and relative importance of the Earth in the family of bodies which we call the Solar System.

In measuring the distances between the stars we adopted the light-year as our unit, but this is obviously too large for measurements within the Solar System, so it is customary to use the Earth's radius as the unit in this case. It is also convenient when comparing the weights of the different planets to use the Earth's mass as unity.

The Solar System is made up of a great central body, the Sun—which is intensely hot and is about 330,000 times as heavy as the Earth—8 major planets, of which the Earth is one, and a large number of minor planets or asteroids. Several of the planets have satellites like our Moon, which move round them, and one, Saturn, has a remarkable system of rings, of which more on a later page.

As our present business is with the Earth, we will now turn our attention to its place in the system, and to its movements. The planets in order, commencing with that nearest the Sun, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

The mean or average distance of the Earth from the Sun is roughly 93 millions of miles, but the distance is different at different times of the year, and this has some considerable effect upon our seasons, though it is not, of course, their cause. The orbit, or path of the Earth round the Sun, is not a circle but an ellipse, the Sun being at one of the foci. When the Earth is at its nearest to the Sun it is said to be in perihelion, and, when farthest away, in aphelion.

Now the nearer the Earth is to the Sun the faster it moves in its orbit. At the present time the winter in the Northern Hemisphere occurs when the Earth is in perihelion, and that of the Southern Hemisphere when it is in aphelion; and since the Earth moves faster when in perihelion, the Northern winter is shorter than the Southern, and therefore the Arctic winter is not so severe as the Antarctic.

Owing to another movement of the Earth, that called precession, into the details of which we need not enter, the positions of the seasons steadily alter in such a manner that in about 12,000 years the positions will be reversed, and the Arctic winter will be the longer and more severe.

Attempts have been made to explain certain changes of climate which have taken place from time to time during the past history of the Earth by this means, but on the whole it seems inadequate. Of this we shall speak again in a later chapter.

Several of the other planets are larger than the Earth. Jupiter, for example, is 11 times the diameter of the Earth, and Saturn 9 times. This latter planet, as has been already stated, is surrounded by a system of luminous rings which were formerly thought to consist of hot gas, but have now been proved to be multitudes of tiny satellites each moving round the planet in its own orbit. These rings of supposed gas doubtless gave to the French astronomer Laplace his first ideas for his great Nebular Hypothesis, by which he sought to account for the birth of the Sun and planets. This hypothesis and others of later date will shortly be discussed.

We have seen that the Earth on which we live is a comparatively insignificant member of a group of bodies known as the Solar System, which, taken together, form a mere infinitesimal drop in the vast ocean of the visible Universe, our knowledge of whose size is being added to by every improvement in our means of vision.

Most of the bodies in the Universe must have been in existence for countless ages before the Earth, and perhaps even the Sun, was formed. We must therefore disabuse our minds of any idea that we are the centre and purpose of all things, and that the Sun was made to give us light by day, and the Moon by night, and approach the study of these vastnesses in all humility, considering this fact and that, sifting out truth from mere supposition, and remembering that our theories are only theories, and that if they fail to stand the test of time and the accumulation of new facts, we must be prepared to give them up in favour of others.

Origin of the Planets.—Many years ago Laplace brought forward his great theory of the origin of the Sun and planets, and this, which became known as the Nebular Hypothesis, has remained perhaps in some slightly modified form the accepted view until quite recently, when considerable doubt has been thrown upon it by several astronomers, but particularly by Moulton, a citizen of the United States of America.

Laplace supposed that all the matter now contained in the Sun and planets was once so hot that it was all in a state of gas, and that in consequence of its great heat it glowed as do some of the nebulæ.

Under these circumstances he supposed that the gas settled down under the law of gravitation into a vast sphere, much denser towards its centre than on its surface, and that this sphere was slowly revolving in the same direction as the planets now move round the Sun. The circumference of the sphere was greater than the orbit of Neptune, which has a radius of 2800 millions of miles. Under the influence of its rotation the sphere became slightly flattened at its poles and developed a slight bulge around its equator.

The sphere of gas was slowly losing its heat into surrounding space, and this brought about a fall of temperature and a gradual shrinking, so that it grew slowly smaller and smaller, and as a consequence it rotated faster and faster.

This can be illustrated by tying a small weight or stone to one end of a string, attaching the other end to a stick, and then whirling it round so as to allow the string to wrap round the stick, thus shortening the radius of swing of the stone. It will be seen that as the free portion of the string becomes shorter the stone moves faster.

If we could whirl the stone sufficiently quickly the string would break and the stone would fly off, because the centrifugal force had become greater than the tensile strength of the string.

In the great revolving nebula the force of gravity took the place of the string, and Laplace thought that as the sphere shrank and the motion became faster, a stage was reached when the centrifugal force in the bulge round the equator of the sphere became equal to the force of gravity.

Under these circumstances the bulge ceased to shrink towards the centre, while the main mass continued to do so, and thus the bulge was left behind in the form of a ring.

This ring afterwards broke and formed a planet, Neptune, which was itself rotating on its axis and was at first gaseous. The process of ring-making was repeated in the planet, the rings in this case giving rise to satellites.

Meantime the main mass of the nebula continued to shrink towards its centre, leaving behind it ring after ring, each one of which formed a planet, until eventually the nucleus contracted and formed the Sun, which contains by far the greater part of all the matter in the system.

Such, then, is Laplace's Nebular Hypothesis, and it appears extremely probable that it was first suggested to him by the rings of Saturn, which he looked upon as satellites in course of formation. The fact that these rings have been shown to consist of small satellites, and not of gas, removes observational support for the theory, and astronomers have recently stated that such a mode of formation of the planets is quite out of accord with all established laws of mechanics.

So serious are these objections to Laplace's theory that it appears to be no longer tenable, and therefore some other must be sought. It may be mentioned that the objections to Laplace's theory, which are chiefly of a mathematical nature, apply equally to the meteoritic hypothesis of Lockyer and its modifications.

Under these circumstances Professor T. C. Chamberlin of Chicago brought forward the Planetesimal

Hypothesis. His view is that a central body, possibly cold and dark, formerly contained all the matter now distributed between the Sun and the planets and satellites which now constitute the Solar System, and that this central body was broken up by the attractive force of a similar body, which, in the course of its wanderings through space, came sufficiently near to produce disruption owing to tidal stresses.

By far the greater part of the matter would appear to have remained in the central body, while two great arms were thrown out on opposite sides of the ancestral Sun, which by the friction was raised to a high temperature and caused to glow. The arms consisted of many-sized fragments of solid matter, together with much gaseous matter, the solid fragments being scattered quite irregularly through the arms, here in dense swarms, there few and far between.

The arms eventually became coiled in spiral form, producing a spiral nebula similar to those which have been revealed by our telescopes in enormous numbers throughout the Universe.

It has been proved that, under the conditions supposed, the various masses thus scattered through surrounding space by the disruption of the ancestral Sun would soon come to travel in elliptic orbits round the remnant of the central mass.[1]

The matter in the arms of spiral nebulæ is known to be distributed irregularly, there being many knots in the arms. The knots in the arms of the Solar Nebula are

[1] For further particulars of the Planetesimal Hypothesis the reader is referred to volume ii. of Chamberlin & Salisbury's *Geology*, where a full and lucid account of it will be found.

considered to have formed the nuclei of the planets, which have since increased in size by the gathering in of the smaller scattered fragments through the course of the ages. Chamberlin considers that the gathering in of the planetesimals, as he designates these tiny planets, is still in progress, and regards the meteorites which enter our atmosphere at the rate of many hundreds a day as belated planetesimals.

This planetesimal hypothesis does not necessitate the occurrence of extremely high temperatures in the Earth's interior, though doubtless much heat would be evolved during the compression of the original nucleus, as layer upon layer of planetesimal matter was added to its surface.

The distribution of temperature in the outer part of the solid Earth would render it certain that exceedingly high temperatures must occur near the centre were it not for recent discoveries which make it unnecessary to believe that the Earth-heat is merely the residuum of an original supply imparted to it as the result of central compression or otherwise.

The knowledge that has been added to our store by the discovery that radium and certain other elements which act in a similar manner are continually producing heat, and that these elements are present in many ordinary rock materials, justifies us in concluding that here is a considerable source of heat which must profoundly affect the underground temperature gradient, and invalidate any calculations as to internal temperatures, based on the supposition that the present distribution of temperature is due to the simple cooling of a heated Earth.

An examination of specimens of many different kinds of rock from numerous sources shows that in all probability the radium in the Earth yields enough heat to compensate for the loss by radiation into space, and that therefore the Earth may not be cooling at all; it may be indeed slowly rising in temperature.

Thus the Geologist is no longer bound by beliefs in a high internal temperature involving a gaseous or liquid centre, nor is he strictly limited to a calculated duration of geological time, which has long been thought utterly inadequate either for the working out of the enormous changes through which the rocks have passed or for the evolution of plants and animals from primeval types.

Though, as has been stated, these matters belong to the domain of the Astronomer and Physicist, Geologists may not ignore them, as they affect profoundly many purely geological matters.

Many of the older Geologists believed that mountain chains were produced by the shrinking of the liquid or gaseous interior of the Earth as the result of cooling, and the consequent wrinkling of the hard crust, and that volcanoes were supplied with molten lava from the great liquid interior.

Clearly, if there is good reason to believe that the great mass of the Earth is solid, other means must be found of accounting for these phenomena. Again certain very ancient crystalline rocks, known as gneiss, were at one time considered to be parts of an original crust formed on the surface of a molten sphere much as ice is formed on the surface of a lake in winter, but if the Earth was formed by the accumulation of cold and solid planetesimals, it is obvious that some modification of this view is necessary.

At the present time there is much diversity of opinion as to the way in which life first appeared upon the Earth. Some men of science still hold the view that there is a fundamental and essential difference between living and non-living matter, while others maintain that ere long the production of the animate from the inanimate will merely be a question of chemical and physical manipulation, and that the so-called spontaneous generation of life may be going on all around us without our having discovered it as yet.

It has been recently demonstrated that the eggs of the sea-urchin can be caused to develop into complete animals in the absence of the male element, and it has also been stated with good reason, that should we succeed in producing living from non-living matter, so simple might be the type, and so obscure its activities, that we might not at first recognize it as possessing the properties and activities which we associate with the idea of life.

Be that as it may, and time will undoubtedly bring forth the truth of the matter, at some remote period in the Earth's history living matter appeared upon its surface, and it is the general belief of those who have applied scientific methods to the investigation of such matters, that all the varied forms of life, both plant and animal, not excluding the higher animals, of which man is one, have by a slow and gradual process of evolution developed from this primeval living matter, newer and more highly specialized types coming into existence in response to various stimuli imparted by changing conditions of general surroundings, such as climate, the competition for food and habitation, and the general struggle for existence.

CHAPTER II

THE ATMOSPHERE

THERE are many facts connected with the atmosphere, a knowledge of which are essential to the proper understanding of some of the more interesting portions of our subject, and for that reason we shall now proceed to study certain aspects of meteorology.

Surrounding the solid Earth is an envelope of gas which we call the atmosphere, and which is variously estimated at from 150 to 200 miles in thickness. It is very difficult to measure the thickness or depth of the atmosphere since we live at the bottom of it, and it is not nearly so easy to take soundings upwards in a sea of gas, as it is to take them in the case of oceans of water from the top downwards.

For a similar reason it is not easy to determine the conditions in the upper regions of the atmosphere, and we must rely on such observations as can be made from the tops of high mountains and from balloons and aeroplanes, coupled with the application of known physical and mathematical laws, for information concerning them.

The atmosphere is made up of a mixture of gases which we call air, consisting of oxygen 20·8 parts by volume, nitrogen 79·2 parts by volume, and variable though much smaller quantities of carbonic acid and water vapour.

The oxygen is an invisible gas without any noticeable colour, is an extremely active chemical element, and serves for the breathing of animals and the combustion of many substances such as wood and coal. It is found not only in the atmosphere, but in combination with another gas, hydrogen, forms the substance water which plays such an important part in the activities of the Earth and its inhabitants.

Oxygen is also found, in combination with other elements, in many minerals and rocks, and thus forms part of the solid Earth also.

The nitrogen in the air is an inert body; it does not enter readily into chemical combination with the other constituents of the atmosphere, though it can be made to do so under certain conditions, and occasionally combines in small quantities with the oxygen when a lightning flash occurs.

By the agency of minute bacteria which are to be found upon the roots of peas, beans, and certain other plants, the nitrogen is caused to combine with oxygen and other elements to form the compounds called nitrates, which perform an important part in the economy of plants.

The carbonic acid, though normally present in quantities not greater than 35 parts in 100,000 parts of air, nevertheless, is absolutely essential to the life of plants and animals, and is responsible for setting in motion very many of the chemical changes which take place during the rotting away of rocks under the influence of the atmosphere—a process usually spoken of as weathering.

It must, therefore, be regarded as an essential constituent of the atmosphere, and can only be regarded as an impurity when present in quantities considerably greater than the normal amount, as it frequently is in large cities, or in crowded rooms, owing to its being formed by the burning of wood and coal and by the respiration of animals.

Most plants have the power of absorbing the carbonic acid from the atmosphere, and, with the aid of sunlight, of decomposing it, using up the carbon which it contains to build up their woody tissues, and giving back the oxygen, at least in part, to the atmosphere.

Carbonic acid is soluble in water, and is, therefore, caught up by falling raindrops, and it is this dissolved gas in rain-water which brings about many of the changes alluded to above as weathering, while it is also responsible, as will be seen later, for the formation of caverns in limestone countries.

From such observations as have been made, it would appear that the quantity of carbonic acid in the lower parts of the atmosphere is much greater than that at higher levels, and this fact, as the sequel will show, has a very important bearing on the temperature of the upper and lower portions.

The water vapour which is in an invisible form is very variable in amount. The quantity of water vapour which air is capable of holding depends upon the temperature. The higher the temperature the more water vapour it can hold. If, therefore, a quantity of warm, moist air is cooled, some of the water will appear in the liquid form, as cloud, fog or dew.

In common with all other gases, air when heated expands, and therefore becomes lighter, as there is only the same amount of matter in a larger space. This is an everyday experience, as it is responsible for the rising of hot air and smoke from our chimneys, and for the accumulation of hot air near the ceilings of our rooms. The action can also be seen in the case of the paper fire-balloon used in connection with galas and firework displays.

It is a matter of general knowledge, that certain parts of the Earth's surface receive a much more generous supply of heat from the Sun than do others, and this fact is responsible for the movements of the air which we call winds.

First, let us consider the state of affairs at one of the two periods of the year when the Sun is immediately overhead at the equator, known as the equinoxes.

At these periods the regions in the vicinity of the equator will be much more strongly heated by the Sun's rays than regions more remote, and consequently the air in the equatorial belt will, by reason of its expansion, become lighter than that in the regions to the North and South. The heavier air in the cooler belts will, therefore, flow in towards the equator, displacing and floating upward the air of the equatorial belt.

Near the surface of the ground, therefore, we shall find air currents or winds, flowing from northerly and southerly directions towards the equator. The warm equatorial air pushed upwards by them overflows the colder currents, and thus comes to move outwards from the equator towards the poles.

The polar regions at this time receive practically no heat from the Sun as it is on the horizon during the whole twenty-four hours, and the air therefore becomes chilled, contracts, becomes heavier, and therefore tends to descend towards the surface. Thus a circulation is set up, upwards at the equator, outwards in the higher regions towards the poles, downwards in the polar regions, and back along the surface towards the equator.

The current of air along the surface, from poles towards equator, tends to carry the mass of the atmosphere in that direction, while the pole-ward currents in the upper air tend to shift it in the opposite sense. These tendencies balance each other in the regions of the tropics of Cancer and Capricorn (latitude 23½° North and 23½° South respectively). Owing to this, the pressure of the lower part of the atmosphere is highest in the regions of the tropics, and the effect is to complicate the circulation, and to produce surface winds from the tropics towards the poles (Fig. 1).

An examination of the diagram will show that at the equator the air currents are moving upwards and at the tropics downwards, consequently to persons situated on these lines there would appear to be no wind. These are the regions known to navigators as the calms of Cancer, the Doldrums, and the calms of Capricorn.

On the supposition that the Earth did not rotate upon its axis, and that it was entirely covered by the waters of the ocean, this would be the state of things at the equinox, while between the tropic of Cancer and the equator there would be constant north winds, and from the tropic towards the Arctic Circle constant south winds, gradually dying away towards a polar calm with descending air currents.

In the Southern Hemisphere these winds would be reversed; between tropic and equator, south winds would prevail, and north winds from the tropic towards the Antarctic Circle.

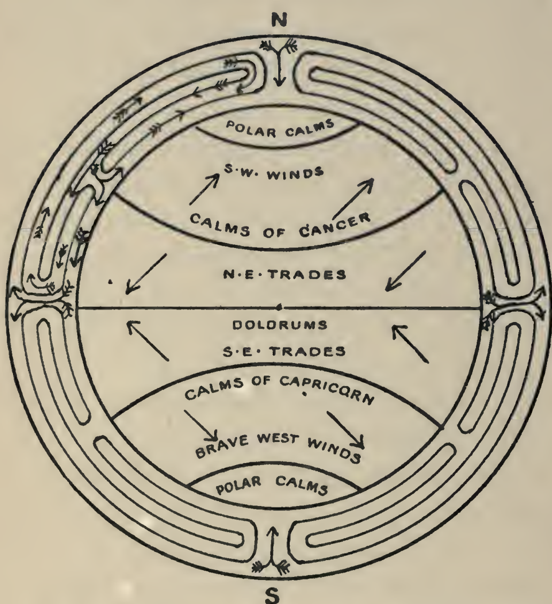

FIG. 1.—Theoretical Circulation of the Atmosphere.

The effect of the seasons on this ideal arrangement would be to shift the zones northward in the northern summer, so that the Doldrums would occupy the region of the calms of Cancer, and southward in the southern summer.

An examination of a map of the world will show that there is far more land in the Northern than in the Southern Hemisphere, a circumstance which destroys the balance, and has the effect of shifting the various belts towards the north, as owing to the irregular distribution of land and water the heat-equator, or line of greatest mean annual temperature, lies to the north of the actual equator.

The rotation of the Earth greatly affects the direction of the various air currents, deflecting them from their original courses in accordance with definite laws. The Earth rotates from west to east, and a point on the equator naturally moves towards the east with a greater velocity than a point, say, on the tropic of Cancer. The air in contact with the Earth is carried round with it owing to the friction, but air flowing from a region of lower easterly velocity, such as the tropic of Cancer to one of higher velocity, does not immediately take up the speed of the latter. It gets left behind, and thus an observer midway between the tropic of Cancer and the equator, in the region of north winds, would be carried through the air towards the east. This would give the impression of a wind from the east, which, combined with the wind from the north, would produce a north-east wind. Similarly in the Southern Hemisphere the south winds are transformed into south-east winds.

These winds covering the belts between the tropical calms and the Doldrums blow constantly in the same direction, and are known as the north-east trade winds and the south-east trade winds.

For similar reasons the southerly winds to the north of the tropic of Cancer become south-westerly winds, and the region is known as that of the Prevailing South-Westerlys, while the corresponding area in the Southern Hemisphere has winds from the north-west known as the Brave West Winds.

The region in the immediate neighbourhood of the equator has been spoken of as a region of calms—the Doldrums—but along the coastal belts there are often strong breezes, which blow from the sea during the day and from the land during the night.

These winds are due to a difference between what is called the "specific heat" of the water and that of the land. The specific heat of a substance is the quantity of heat which is necessary to raise unit mass of the substance one degree in temperature, and it differs very considerably for different substances.

Water possesses a much higher specific heat than does rock, and the result of this is that during the day, while the Sun is pouring down heat upon sea and land alike, for each unit of heat received the rocks rise more in temperature than does the water of the ocean. Thus the air over the land gets hotter, and therefore lighter, than that over the sea, which flows in, as a sea breeze, the air over the land rising.

In the evening, for similar reasons, the land cools more quickly than the sea, so that some little time after sundown the wind will fall calm, and later spring up in the opposite direction as a land breeze.

Far more important than these land and sea breezes of the tropics are certain winds which prevail in the Indian Ocean, in Southern Asia, and several other parts of the world. These are the Monsoons or seasonal winds, and are produced owing to the fact that in the regions between longitude 40° E. and 120° E. there is an enormous preponderance of land in the Northern Hemisphere.

The effect of this is that during the northern summer the great land mass of Asia gets heated up more quickly than the oceanic area to the south, and consequently winds from the south are set up, and these, deflected by the Earth's rotation, become the South-West Monsoon which carries the summer rains to India.

In the northern winter the Continent cools the more rapidly, and a north-east wind results.

Here, then, is a part of the world in which the climatic conditions normal to the latitude are completely overridden by others set up by the configuration of the land, and as we know that the distribution of land and water has been very different in the past, we may have in this an explanation of some at least of the climatic changes which parts of the Earth's surface have undergone during the geological periods.

We have seen that the amount of moisture which the air is capable of holding depends upon its temperature, and anything which brings about a lowering of this temperature will therefore tend to cause the deposition of water in the form of rain or dew.

One of the principal causes of rainfall is the cooling which takes place when air is caused to expand.

When a gas expands a part of its heat is used up in bringing about the expansion, and the temperature consequently falls, unless a further supply of heat is provided from outside. Similarly, when a gas is compressed it immediately becomes warmer.

Let us now see how this will affect the distribution of rainfall over the Earth's surface, and for this purpose we will again refer to the diagram Fig. 1. Over the equator it will be noticed that the air is rising, that is, it is passing from a region of high pressure to one of lower pressure. This being the case, it will, of course, expand and consequently become cooled and deposit its excess of moisture.

For this reason the Doldrums is a region of heavy rains, which in any place are seasonal, occurring twice a year, as the Sun passes and repasses on his northward and southward journeys.

Very different are the conditions in the regions of the tropics of Cancer and Capricorn, where the cold, dry air currents are descending and therefore undergoing compression, and a rise of temperature. They reach the surface as currents of warm, dry air, and cause excessive evaporation in their respective regions.

It is here that all the great desert regions of the world are to be found. In the Northern Hemisphere we have the Sahara, the deserts of Arabia and India, and of Colorado, and the neighbouring parts of the United States.

In the Southern Hemisphere the deserts are not so well marked owing to the preponderance of oceanic over continental areas, but they are nevertheless to be seen in the Great Central Desert of Australia, the South African Desert, and the dry pampas of South America.

The effect of a mountain chain upon rainfall is similar in principle. The warm, moist air from an ocean blows towards the land and encounters a mountain chain which it must cross. To do this, the whole current must rise, and will therefore reach a region of lower pressure. Expansion, cooling, and precipitation of moisture are the natural results, and thus we get heavy rainfall on the windward slopes of our mountains.

On the lee-side of the mountains, the air current, having lost its excess of moisture, flows down the mountain slopes into the regions of higher pressure below, and it consequently becomes compressed and warmed, as in the case of the downward currents of the tropics, producing dry areas under the lee of the chain.

Here, again, we may have a means of explaining some of the climatic changes which have occurred during the Earth's history as the mountain chains of one Geological Period have certainly not occupied the same positions as those of another.

CHAPTER III

THE HYDROSPHERE

One of the first impressions that one gets on visiting the coast-line of a country is the vastness of the ocean. It stretches away to the horizon, and if we ascend a hill or high cliff and look seawards, it only appears vaster still.

Standing, for example, on the Land's End in Cornwall, or on the cliffs of the west of Ireland, we can look away towards the west and see nothing but the apparently limitless waste of waters, and should we sail away from the shores of these islands, we can travel westward for a week at the speed of an ordinary train without reaching its farther boundary.

The waters of the ocean do not, of course, cover the whole of the Earth's surface as is the case with the atmosphere which was described in the last chapter, being gathered together under the influence of the laws of gravitation in the great hollows, forming oceans and seas.

These submerged areas form nearly three-quarters of the whole surface, and have been divided by the late Sir John Murray into an abyssal area from two to five miles deep, covering one-half of the total area of the planet, and a transitional area of comparatively shallow water covering three-sixteenths. The remaining five-sixteenths is the continental land, which has an average elevation of 900 feet above sea-level.

The form of the ocean floor is of some considerable interest, and one of the least anticipated facts is, that the greatest depths are found, not in the middle of the basins, as might be expected, but usually quite near the land. The greatest depth so far recorded in the Atlantic Ocean is only about 80 miles from the Bermudas, and is 3875 fathoms, but greater depths have been recorded in the Pacific, off the coast of Japan, again near the land, where a sounding of 4655 fathoms was taken in what is known as the Tuscarora Deep, from the name of the United States surveying vessel which discovered it.

The greatest depth yet recorded is near the Kermadec Islands, and about 300 miles north-east of East Cape in New Zealand. Here a depth of 5155 fathoms, or nearly 6 miles, was reached.

It is by no means an easy matter to make soundings in extremely deep water, and much ingenious apparatus has been devised for the purpose. The simplest form consists of a weight attached to a cord. The weight is thrown overboard, and the line paid out, until it is felt to slacken owing to the weight having reached the bottom. The length of line used will then, of course, indicate the depth. When greater depths are to be measured, the weight of the line becomes so great that it is difficult, if not impossible, to tell when the sinker has reached the bottom, and so a heavier weight has to be used. There is, of course, a limit to this increase of weight, as if it is taken beyond a certain point a stronger cord will be required to support it, and this will, of course, weigh more, and so the old difficulty will recur.

There is also another difficulty to be overcome—when far out at sea, out of sight of land, it is impossible to tell whether a ship is stationary or drifting slowly with some surface current. If the ship is drifting the sounding line will trail out astern, for the currents are, as a rule, only near the surface, and thus the sinker will reach the bottom obliquely, and the length of line will no longer be a measure of the depth. Several devices have been invented to overcome these difficulties, of which the following are a few.

It is often desirable that information should be obtained with regard to the nature of the materials of which the sea floor is made up, and therefore the sounding apparatus is usually constructed in such a manner that it brings up a sample of the bottom for examination.

In the simple lead which is used by ships approaching the land in foggy weather, this object is secured by making the lower end cup shaped, like the bottom of a wine bottle, and, before casting the lead, partially filling the cup with tallow. When the lead reaches the bottom, some of the sand, mud, or other material sticks in the tallow and can afterwards be removed and examined. If no loose material is found in the tallow, it is assumed that there is a rocky or "hard" bottom.

When greater depths have to be reached, it becomes a matter of some importance to minimize the labour of hauling up the apparatus, and for this purpose several kinds of machine are in use in which the weights are detached automatically on reaching the bottom, and only the inner part, consisting of a metal tube provided with a valve at its lower end, so as to retain a sample of the bottom, is again brought to the surface. In this form of apparatus a strong wire is used in place of the cord or rope, and being thinner and therefore offering less surface to the water, there is less tendency for it to trail out obliquely or be deflected by currents.

When dealing with very great depths even these forms of apparatus were found to be unreliable, as it was impossible to ascertain if the machine had gone straight down, and therefore an appliance which would tell the depth independently of the length of line used had to be devised.

The late Lord Kelvin invented a most ingenious form consisting of a strong glass tube closed at one end and similar to those in use in barometers. The tube was coated on the inside with chromate of silver, a reddish-brown substance, and was placed in the sounding machine with its closed end uppermost. When this was lowered into the sea, the water would not at first enter the tube far beyond its mouth, but as it sank deeper and deeper the pressure would gradually increase and the water would be forced farther and farther up the tube, gradually compressing the air in the closed end.

Now, sea water, as everyone knows, contains common salt, or chloride of sodium, and this acts upon the chromate of silver in the tube, forming chloride of silver, which is white.

As the machine, having dropped its heavy sinkers at the bottom, is hauled up, the sea water will again be forced out of the tube by the bubble of compressed air, but when it reaches the surface we can tell how far up the tube it has been by seeing how far up the red lining of the tube has been turned white. From the height to which the water has been forced, the pressure at the bottom of the ocean can be ascertained, and from this it is easy to calculate the depth.

The modern forms of instrument consist of a metal pressure gauge, which registers automatically the highest pressure to which it has been subjected, and thus gives us a measure of the depth, without our having recourse to the length of wire paid out.

Round the edges of the continents there is usually a submerged plateau, sometimes called the "continental shelf," and this varies very much in width. The water upon it is usually shallow, and its slope is very gradual. At the edge of the "continental shelf" the slope becomes much more steep, and the transition to deep water is consequently rapid.

If we go westward from the coast of Ireland we find that the ocean floor falls about 6 feet per mile for the first 230 miles, then, the slope suddenly changing to 450 feet per mile, it drops 9000 feet in the next 20 miles, beyond which the bottom is fairly level but gently undulating, until a similar shelf is met with near the American continent.

Some idea of the total bulk of the oceanic waters may be gained by comparing it with that of the land above sea-level. If we could shave off the continents and islands of the world down to sea-level, and transport the materials of which they are built into the Atlantic Ocean, they would scarcely suffice to fill up one-third of it, leaving the great Pacific, Indian, and

Antarctic Oceans untouched. From the surveys that have been made, it has been calculated that the cubic content of the oceans is about fourteen times as great as that of the dry land.

As a general rule the oceanic areas of the Earth are warmer than the continental areas in the same latitude, but we must not suppose that the whole of the ocean waters are warm. As a matter of fact, the waters of the ocean depths are exceedingly cold, and only the surface waters, as a direct result of the absorption of radiant heat from the sun, are warm. This distribution of temperature has a very important bearing on the distribution of life in the ocean depths.

In the tropics the surface temperature of the ocean reaches 84° Fahr., but the layer of warm water is not deep, as the following figures relating to the Pacific will show :—

Surface	80°–84°
100 Fathoms	60°
200 "	50°
500 "	42°
1000 "	36°
Bottom	32°–33°

The temperature of the waters of the ocean sinks with fair rapidity down to a depth of 500 fathoms, at which the temperature is fairly uniform and about 40°–45° Fahr. As we pass still farther downwards, the temperature falls slowly until in the greatest depths it falls below the freezing-point, but as salt water solidifies at a lower temperature than fresh, it still remains in the liquid form.[1]

[1] The freezing-point of sea water is 28½° Fahr.

Thus, in spite of the fact that the surface temperatures are on the whole higher on the sea than on the land, the great oceans are filled to more than three-fourths of their capacity by water whose temperature is very near the freezing-point, *i.e.* considerably lower than the normal temperature of the rocks which form the ocean floor.

Under these circumstances we should expect that the waters of the deep basins would be slowly warmed up, and this would undoubtedly be the case were it not for the fact that cold water is heavier than warm water, and that as a consequence a circulation similar to that in hot-water heating apparatus is set up.

The great oceans are all open to the southward, and therefore in communication with the Antarctic Ocean, where even at the surface the temperature of the water is near the freezing-point. They are also, though to a considerably less extent, in communication with the Arctic Ocean.

From these two oceans, but principally from the Antarctic, the cold water flows slowly along the bottom towards the equator, displacing and floating upwards the warmer waters of the tropics, which in their turn flow outwards from the equator towards the poles, thus completing a circulation not unlike that which we have already traced in the atmosphere.

The surface currents of the ocean are, however, also greatly influenced by the winds, and, indeed, so powerful are some of these wind-produced currents that they obliterate the convection circulation described in the last paragraph.

It is the cold bottom currents mentioned above which keep up the supply of cold water to the great ocean depths, and where the basins are enclosed, or partially so, by elevated ridges of the sea floor, some very interesting facts have been observed. For example, in the two great basins of the North Atlantic the temperature at 2000 fathoms is 35°, and there is no further decrease at greater depths, the whole of the water below the 2000-fathom line being at the same temperature. In contrast to this is the depression off the coast of Brazil, in which the temperature decreases steadily to the bottom, where it reaches 33° Fahr.

The difference is due to the fact that the basins of the North Atlantic are separated from the cold Antarctic waters by a ridge over which the water is nowhere more than 2000 fathoms deep, and which prevents the influx of waters at lower temperatures than that appropriate to that depth, while the Brazilian basin is freely open to the south.

This phenomenon is still more marked in the case of enclosed seas like the Red Sea, where the temperature falls rapidly down to a depth of about 200 fathoms, where it is 70°, and does not fall below this even where depths of 1200 fathoms are met with.

The high temperature of the great mass of the waters of the Red Sea is undoubtedly due to the shallowness of the Straits of Bab-el-Mandeb, which prevents the influx of the cold polar waters. The diagram Fig. 2 will make this principle clear when we remember that the lower the temperature of the water, the heavier it becomes.

We have already had occasion to mention the surface currents of the ocean, and as these are the only ones which are directly apparent, and which influence climate and to some extent also navigation, they are the ones usually indicated by the term "ocean currents." Any good atlas will contain a map showing the distribution and direction of these currents, but it is of considerable interest to inquire into their causes, and for this purpose it may be well to study in some detail the currents of one ocean, say, the Atlantic.

It will be seen from the sketch map Fig. 3 that there is a broad westerly-flowing current in the neighbourhood of the equator. This is really two currents—the Northern

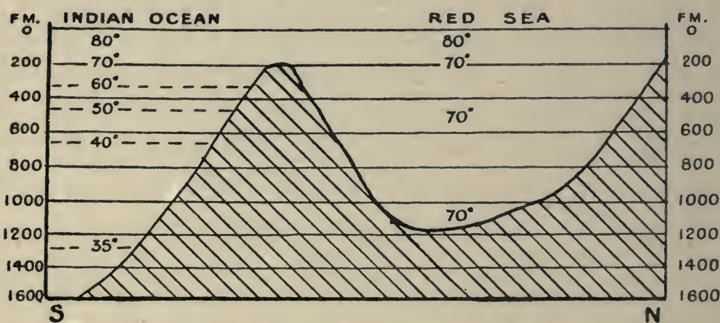

FIG. 2.—Diagram to illustrate the Temperatures of the Indian Ocean and the Red Sea.

Equatorial and the Southern Equatorial—separated from one another by a smaller and somewhat variable easterly-flowing current, variously known as the Counter and the Guinea Current.

For the purpose of investigating the main cause of the currents of the Atlantic, we may consider the Equatorial as one great broad westerly-flowing stream which, when it reaches the South American continent in the neighbourhood of Pernambuco, divides into two, one passing to the north-west along the coast of Brazil, past the mouth of the Amazon, and thence along the coast of Guyana to the neighbourhood of Georgetown. Here

FIG. 3.—Diagram to illustrate the Currents of the Atlantic.

it again divides, the major portion flowing in a north-westerly direction outside the Windward and Leeward

Islands and the Bahamas, and then curving towards the north between the Bermudas and the coast of Florida.

The other portion of the Northern Equatorial Current passes between the Windward Islands and Trinidad into the Caribbean Sea, and thence through the Strait of Yucatan into the Gulf of Mexico, whence it eventually emerges by the Strait of Florida as the Gulf Stream, which amalgamates with the portion which flowed outside the Antilles, already described.

The combined stream then flows up the coast of Florida to the neighbourhood of Savannah, when it leaves the coast and flows to the north-east across the Atlantic towards the British Isles. A small branch breaks away from the main stream about N. latitude 50° and flows along the west coast of Greenland by Davis Strait into Baffin Bay. The main stream again divides in mid-Atlantic, one part flowing between Iceland and Scotland, and the other turning southward along the Spanish and African coasts, to again join the Northern Equatorial Current. In the interior of the closed curve thus produced is an area devoid of currents, known as the Sargasso Sea—a region which, occurring as it does in the Calms of Cancer, was much dreaded in the days of sailing vessels as they were frequently becalmed there, and many are the thrilling "yarns" which have been spun about the horrible monsters which were believed to inhabit these waters.

Now, to return for a moment to the Southern branch of the great Equatorial Current. This flows southward along the coast of Brazil, and is known as the Brazil Current. About the latitude of Buenos Aires the current turns eastward and flows across the South Atlantic towards the Cape of Good Hope, and then northward (the Benguela Current) to rejoin the Southern Equatorial Current.

It will thus be seen that there is a roughly circular arrangement of the currents in both the northern and southern basins, but while in the former the movement is in the same direction as that of the hands of a clock, in the latter the circulation is counter-clockwise. This is due to the Earth's rotation, and can be explained by the application of the same principle as was employed in the case of the winds (see page 35).

Of the above, the Equatorial Current, the Gulf Stream, and the Brazil Current are all warm, while the Benguela is cold, being partly supplied by the waters of the Antarctic Ocean.

There is in the North Atlantic a cold current of considerable interest. It is the Labrador Current, and flows from Baffin Bay through Davis Strait in a southerly direction. On reaching Cape Race in Newfoundland it turns sharply to the south-west under the influence of the Earth's rotation and flows along the coast of Nova Scotia, and then southward between the Gulf Stream and the American coast.

It is the Labrador Current which carries down the great icebergs from the frozen north, which are such a serious menace to our shipping, and these, melting as they enter warmer regions, by dropping their burdens of earth and stones, contribute largely to the Great Bank of Newfoundland.

The chilling effect of the ice and the cold waters of the Labrador Current upon the warm, moist winds blowing from the warmer waters of the Gulf Stream is responsible for the dense fogs which so frequently prevail off the coast of Newfoundland, and which render the presence of floating ice still more perilous.

There seems to be little doubt that the climate of Labrador, Newfoundland, and Nova Scotia is colder than what is normal for the latitude, owing to the influence of this stream of cold water.

The circulation in the Pacific Ocean is strikingly similar to that of the Atlantic, as reference to a map will show, and as the shapes of the two oceans are very different, we must look for some other cause to explain the likeness.

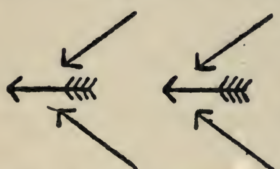

FIG. 4.—The feathered arrows represent the direction of the ocean current, the unfeathered those of the winds.

There can be little doubt that the movement is primarily set up by the action of the trade winds upon the surface of the waters. These winds, blowing always in the same direction, draw the surface waters along with them, and the two streams produced, meeting, follow a mean direction towards the west (Fig. 4). It is obvious that these winds are a competent cause of the circulation, which is a purely surface phenomenon and does not affect the deeper waters, but if any proof be required, it is forthcoming in a comparison of the currents of the Atlantic and Pacific with those of the northern part of the Indian Ocean where, as has already been seen, the trade winds do not prevail, but are replaced by the monsoons. Here the currents are variable and ill-marked, flowing at one season in one and at other times in the opposite direction.

It now remains to consider the origin and effects of the tides, phenomena so general in their distribution and so well known as to need little in the nature of description.

Sir Isaac Newton, after prolonged study of natural phenomena, enunciated certain laws which govern not only the motions of the planets, but apply also to the most minute particles of matter, and one of these laws, known as Newton's first law, runs as follows: Every particle of matter in the Universe attracts every other particle with a force proportional to its mass, and inversely proportional to the square of the distance between the particles. This is usually expressed in the form of an equation thus—

$$F = \frac{M_1 \times M_2}{d^2},$$

where F is the force, M_1 and M_2 the masses of the particles, and *d* the distance between them.

Now, suppose we have two particles each having a mass of 1 and separated from each other by a distance of 1, we shall then have—

$$F = \frac{1 \times 1}{1^2} = \frac{1 \times 1}{1 \times 1} = 1.$$

If, however, we make the distance between the particles 2, then—

$$F = \frac{1 \times 1}{2^2} = \frac{1 \times 1}{2 \times 2} = \frac{1}{4}.$$

Similarly, if the distance be increased to three units, $F = \frac{1}{9}$, and so on.

Now we know that it is the attraction of the Sun which prevents the Earth flying off at a tangent to its orbit into space, and according to Newton's law the Moon and the planets must also attract the Earth, and it can readily be shown that these attractions actually exist.

Now, if we consider the attraction of, say, the Sun on the waters of the ocean on the side of the Earth nearest to it, it will be obvious that these will be drawn more strongly towards the Sun than the solid Earth, which is farther away, and that the solid Earth will be pulled more strongly than the water on the far side. The Moon produces a similar effect on the waters, but for reasons presently to be explained, the tide-raising power of the Moon is greater than that of the Sun, although its total attraction is, of course, far less.

In the diagram (Fig. 5) and the following calculation the distances are measured in terrestrial radii, and the masses of the Sun and Moon are expressed in terms of the Earth's mass.

The attraction of the Moon on the waters on the side of the Earth nearest to it will be proportional to $\frac{\cdot 0123 \times 1}{(59)^2}$, while that on the waters on the far side will be $\frac{\cdot 0123 \times 1}{(59+2)^2}$. The tide-raising power of the Moon will therefore be proportional to $\frac{\cdot 0123 \times 1}{(59)^2} - \frac{\cdot 0123 \times 1}{(59+2)^2} = \cdot 0{,}000{,}002{,}279$. Similarly the tide-raising power of the Sun will be proportional to $\frac{330{,}000 \times 1}{(23{,}481)^2} - \frac{330{,}000 \times 1}{(23{,}481+2)^2} = \cdot 0{,}000{,}001{,}019$. Thus it will be seen that although the attraction of the Sun upon the Earth is enormously greater than that of the Moon, the tide-raising power of the latter is more effective than that of the former in the proportion of 11 to 5, owing to its greater proximity.

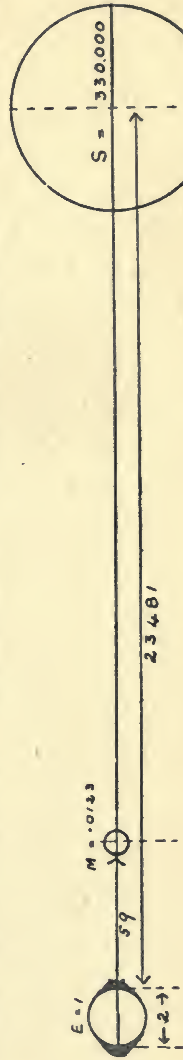

FIG. 5.

At new and full Moon the Sun and Moon are acting together, and tend to produce high water at the same places, and the Solar tide is therefore added to the Lunar tide, with the result that the waters rise higher than at other times, and what are known as "spring-tides" are produced.

At first and third quarter, however, the Solar tide is, so to speak, subtracted from the Lunar tide, and at such times there is little rise and fall of the water, and thus "neap-tides" result.

The tidal wave in the open ocean is only some 6 feet in height, but as it approaches a coast-line and enters narrow inlets and channels, the friction of the water against the sides and bottoms of these channels retards the forward motion of the wave, and thus the waters tend to be heaped up, and in such places there is, therefore, a much greater rise and fall than in the open sea.

A comparison of the amount of rise and fall of the tide in different places will make this clear—

Open Ocean	5 to 6 feet.
Liverpool	34 ,,
Morecambe Bay	45 ,,
Bay of Fundy	50 to 60 ,,

The rise and fall of the tide causes, in the case of narrow inlets and straits, very strong currents which, as we shall see in a later chapter, have considerable effect upon many geological processes now in progress, and there is no reason to believe that many things to be found in the solid rocks are not due to the action of the tides during periods of the Earth's history now long passed.

CHAPTER IV

THE LITHOSPHERE

HAVING briefly considered the atmosphere and hydrosphere, we will now turn our attention to the solid Earth on which they rest.

A most cursory examination of the country will suffice to show us that the rocks of which the Earth's surface is made up are not of the same character in all places. They differ one from another in colour, texture, hardness, and in the mode of arrangement of their component parts.

Broadly speaking, there are three great classes of rocks differentiated from one another by their mode of origin.

To the first class belong rocks which have cooled from a molten state, such as granite, and the various kinds of lava which are poured out from volcanoes. These are called igneous rocks.

By their decomposition under the action of frost, rain, wind, and other natural agencies, igneous rocks break down into loose granular material (sand, clay, *et cetera*), which, carried away by brooks and rivers, is eventually deposited in some lake or in the sea. Such deposits accumulate layer upon layer, and when they become hardened so as to form rocks, the layers are still apparent. From the fact that these rocks owe their characters to sedimentation they are known as sedimentary rocks, and since they occur in more or less definite layers they are also sometimes called stratified rocks. They form the second of the three great classes.

In mountainous regions and in other places where the rocks of the Earth's crust have been greatly disturbed, and where intense pressure and a high temperature have in consequence been developed, rocks of both igneous and sedimentary origin have undergone changes which have impressed upon them new characters. So profound is the change in some instances that it is impossible to ascertain what the original rock was like before alteration. To these rocks which have had new characters impressed upon them by pressure and heat, the term metamorphic is applied.

Thus we have three great classes of rocks—(1) Igneous, (2) Sedimentary, (3) Metamorphic.

We will now examine some of these rocks with the object of finding out what kind of material they contain, and in what manner their particles are held together, so as to give us a general idea of their structure, leaving the question of the way in which they have been formed until we have had an opportunity of examining them in the field, for it is there, if anywhere, that we shall find the clues which will enable us to trace them to their sources and to read the different chapters of their history.

On examining a piece of granite we at once notice that it is built up of several different kinds of matter. There are some parts which are pink, others which are clear and glassy in appearance, while the whole surface is speckled with dark brown, or almost black, particles which glitter strongly in the light.

If now we break up some of the granite in a mortar we shall be able to pick out pieces which consist entirely of one kind of material, and if these are examined chemically it will be found that the pink is different from the glassy or the dark brown matter, and that each of these possesses a definite and constant composition of its own.

These constituents of constant composition are called minerals, and we can say, therefore, that our specimen of granite is made up of three minerals, which have received names. In granite the three principal minerals are: Quartz, the clear, glassy material; Felspar, which in our particular specimen was pink; and Mica, the dark brown shining specks.

Other igneous rocks which look very like granite, and are easily mistaken for it by the uninitiated, on examination will prove to be made up of different minerals, though possessing a crystalline structure similar to that of granite. A chemical analysis of the powdered rock would readily show that they differ widely from granite in composition, and various names are given to them according to the nature of their constituent minerals, *e.g.* Syenite, Diorite, and Gabbro.

An analysis of our granite specimen shows that it is constituted somewhat as follows:—

Silica (SiO_2)	74·0 per cent.
Alumina ($Al_2O)_3$ . . .	14·0 ,, ,,
Ferric Oxide (Fe_2O_3) . . .	0·5 ,, ,,
Ferrous Oxide (FeO) . . .	1·5 ,, ,,
Lime (CaO)	1·0 ,, ,,
Potash (K_2O)	4·5 ,, ,,
Soda (Na_2O)	4·5 ,, ,,
	100·0 ,, ,,

The minerals, felspar and mica, belong to the class of chemical compounds called silicates, while quartz is free silicic acid (SiO_2). It will be seen from the above analysis that the granite contains a very large percentage of the acid silica, in comparison to the other oxides in the list, which are all basic in chaarcter. For this reason granite is spoken of as an acid rock.

The other rocks named above differ from granite chiefly in containing less silica. Thus a syenite would contain about 58, a diorite 53, and a gabbro not more than 45 per cent.

It has already been stated that igneous rocks have been produced by the cooling of a molten mass, and it may be of some interest to see whether we can produce igneous rocks in this way.

Let us take some of our granite and melt it in a crucible furnace, and then allow it to cool, so that we can examine the material produced and ascertain if it resembles the original granite. On turning out the cooled mass we shall find that instead of a coarsely crystalline rock consisting of three different minerals, we have a homogeneous material resembling green bottle glass, and on submitting it to certain optical tests we shall find that it is in reality a glass. This might be taken as evidence against the view that granite is formed in the manner supposed, but experiments with other mixtures of a more basic character show that, if the cooling is rapid, a glass results, but that, by prolonging the cooling, a finely crystalline mass is produced. Still slower cooling produces larger crystals, and thus we see that the rate of cooling has much to do with the nature of the rock.

In nature we find that when molten rock, of composition similar to that of granite, is poured out from a volcano in the form of a lava-stream, it cools quickly and forms a natural glass called obsidian; but when the same material has filled cracks in the Earth's crust, and the escape of heat has been retarded, it has formed crystalline rocks similar in composition to granite, but much finer in the grain. Granite itself occurs in large masses, and there is often evidence to show that at the time of its consolidation it was covered by thick masses of rock, which prevented the escape of the heat, and so prolonged the period of cooling, and gave time for the formation of large crystals.

The question of the origin of the great masses of igneous rock found amongst the other rocks of the Earth's crust will be further considered in a subsequent chapter.

The sedimentary rocks differ so widely in composition, and may contain such a great variety of minerals, that they have to be classified on other lines than those employed in the case of the igneous rocks.

Both structural and chemical features are taken into consideration in this classification and, to some extent also, mode of origin.

Commencing with the finest-grained sediments, we will now enumerate and describe some of the commoner types of sedimentary rock.

Clay is the name given to extremely fine-grained sediments which contain sufficient water to render them plastic. By the drying and hardening of this material such rocks as shale and slate are produced. Shale can be readily divided into thin flakes along the original planes of deposition, but the case of slate is very different. Originally a deposit of clay, slate has been produced by the effect of great pressure, which has resulted in a structure called "cleavage" that renders it possible to split the rock into thin sheets. The direction of the cleavage has no direct relation to that of the bedding planes.

Slightly coarser kinds of mud give rise to such materials as mud-stones, sandy shales, and fine flagstones, while from sandy deposits we eventually get coarse flagstones, sandstones, and grits.

When river gravels or the shingle beaches of a coastline become consolidated they produce the rock known as conglomerate, of which there are many types differing from one another both in the nature, size, and form of the pebbles, and in the amount and structure of the finer-grained matrix in which they are embedded.

Limestones are, for the most part, the products of animal and vegetable life. The substance matter of limestone is calcium carbonate, and this is, under certain conditions, soluble in water. It is present in a state of solution in most natural waters, including those of the sea and of lakes. Many of the animals and plants which inhabit these waters have the power of absorbing the calcium carbonate and secreting it in a solid condition, as shells or other structures, and it is by the accumulation of whole and fragmentary shells, corals, calcareous seaweeds, and the like that limestone masses are slowly built up on the ocean floors and in other suitable situations.

Coal and lignite, or brown coal, are examples of the formation of rocks by the accumulation and consolidation of plant débris probably, for the most part, in swampy regions.

It is a character of most sedimentary rocks that they still retain evidence of their accumulation layer upon layer. This is most marked when successive beds consist of different material, but even thick deposits of homogeneous materials give evidence of their sedimentary origin by the presence of planes, known as planes of bedding or stratification planes, along which they may be separated into sheets or slabs, and which appear on cliffs and quarry faces as parallel cracks.

In their original position these bedding planes are sensibly horizontal, but very frequently, especially amongst the older rocks of the Earth's crust, they are highly inclined, or in some instances actually vertical.

As we cannot imagine the accumulation of such sediments in highly inclined or vertical layers, we are driven to the conclusion that the rocks have been disturbed after their consolidation, and that the layers have acquired their inclination as a result of movements of the land, a view which is confirmed by the occurrence of strata which have been folded into curves, or even crumpled into zigzag forms, which are often of a most complicated nature.

The inclination of a bed of rock to the horizon is spoken of amongst geologists as its "dip," and is usually expressed in degrees, while the direction of the dip is described with reference to the points of the compass. Thus a seam of coal, or other bed, might dip towards the south at an angle of 10°, and in that case, if exposed in a cutting running in an east and west direction, *i.e.* at right angles to the dip, the seam would appear to be horizontal. This horizontal direction at right angles to that of the dip is called the "strike" of the bed. In cases where a bed of rock is of considerable thickness, lies in a horizontal position or dips at a low angle, and occurs in a comparatively flat country, it may cover a very wide area of the surface of the ground; but where the dip is steep, the rock soon plunges beneath the surface, and is lost to view, the width of the strip of land formed by it decreasing as the dip becomes steeper, until, when the angle is 90°, the width will be equal to the thickness of the bed.

The area over which a rock appears at the surface is called its "outcrop," and the form and area of this depend not only on the angle of dip, but also upon the form of the ground. These technical terms are introduced as their use will greatly simplify much that is to follow.

Since the rocks of a country have been laid down layer upon layer in an approximately horizontal manner it follows, of course, that the lowest layers are older than those above, and in places where the horizontality has been disturbed, and the rocks possess a dip, newer and newer rocks will be traversed as one walks in the direction of the dip.

Often in making a traverse of a country it is found that a sequence of rocks is repeated in inverse order, and in this case the beds have been folded into either a trough (or syncline) or an arch (or anticline), and the upper portions of the folds subsequently removed by the action of the weather (Figs. 6 and 7).

In other cases the rocks in place of folding have broken through in such a manner as to allow the beds on one side to slip down below the level of those on the other, and to such a fracture the name of "fault" is given. Faults usually run across country in lines which are approximately straight, and the fractures are generally nearly vertical. The amount of displacement caused by a fault is called its "throw," and this may vary from inches in one case to thousands of feet in another.

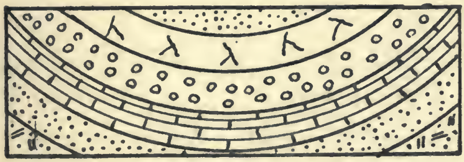

FIG. 6.—Syncline.

It was known to intelligent men as far back as the time of Pythagoras (580 B.C.) that the valleys had been excavated by the rivers that flow in them, and this prepares us for the statement that nearly all the great natural features, mountains, hills and valleys, coast-lines, bays and headlands, even the great continents themselves, owe their present form to natural agents, such as frost, rain, wind, brooks, rivers, and storm waves—known collectively as agents of denudation — wearing away the surface, and by their action upon rocks of diverse resisting power, producing the great variety of physical relief which presents itself to our view.

FIG. 7.—Anticline.

We have seen that in early days many were the speculations as to the origin of natural features, and many wild theories were promulgated to account for them, in most of which deluges, conflagrations, and earthquakes figured largely.

As opposed to this older catastrophic school, the modern geologist believes that most, if not all, of the great physical features have been formed slowly by forces acting quietly, for the most part, through long ages of time.

It was about the middle of the eighteenth century that James Hutton of Edinburgh, who had given much time and energy to the study of the Earth's history, enunciated what is since known as the doctrine of uniformity. His doctrine was simply that the rocks had been produced by agencies still at work, and that the speed at which these agencies acted had not appreciably changed throughout geological time; that the valleys of the past were carved out by the streams just as the streams of to-day are deepening their courses, and that the seas of past periods received the detritus of the land to build up the rocks of the present continents, just as our oceans are elaborating the materials of lands still to come.

In the early part of the nineteenth century William Smith, a civil engineer, discovered a fact and enunciated a principle which has done more to further geological science than anything which had been previously added to our knowledge.

We have already seen that certain aquatic animals contribute largely to the formation of rock materials, and it frequently happens that the whole animal, or some recognizable part of it, is preserved in the mass, thus forming a record of the past inhabitants of the globe. These remains of plants and animals, often converted into substances quite other than those of the original, but frequently retaining much of its structure, are known as fossils. William Smith's great discovery was that the assemblage of fossils in a given group of rocks was always the same, even when it occurred in widely separated areas, while the remains in the group above were different from these, but again constant among themselves.

Thus the rocks of the different geological periods can be identified by their fossil contents, and the rocks of the different continents linked up and correlated one with another.

Charles Darwin and Alfred Russel Wallace, by their independent discovery of the principle of evolution, furnished the explanation of this arrangement of the fossils; the fossil fauna of each bed consisting of the descendants of those below, and being the ancestors of those in the layer above, the time taken for the formation of a group of rocks being sufficiently great to allow of considerable variation in the forms of life.

As an introduction to the chapters which are to follow, a brief account of the geological formations and of the fossils which they contain is here given for the use of those readers who have no previous knowledge of geology.

In the first place, the stratified or sedimentary rocks have been divided in three groups—Palæozoic, Mesozoic, and Cainozoic.

The Palæozoic rocks are those which contain the remains of ancient forms of life, many of the animals having been of very primitive types and having become extinct at the close of the Palæozoic Era.

The Mesozoic Era was characterized by higher forms of life than those of the Palæozoic, but yet different from, and more primitive than, those which exist to-day. These, the middle forms of life, give the name to the Mesozoic.

Many plants and animals similar in type to the present-day or "Recent" fauna and flora came into existence in the Eocene Period, the earliest period of the Cainozoic Era. The word Cainozoic indicates "recent life."

The rocks of each of these great groups are subdivided into "formations," each marked by the presence of certain well-defined groups of fossils, and the formations are in their turn divided into "series," which again possess a characteristic fauna.

The following table will indicate this mode of classification and at the same time serve for purposes of reference. The newest rocks have been placed at the top and the oldest at the bottom, as that is the position in which they occur in the Earth's crust.

THE GEOLOGICAL RECORD

Cainozoic	Recent Pleistocene Pliocene Miocene Oligocene Eocene	
Mesozoic	Cretaceous . . .	Chalk Upper Greensand Gault Lower Greensand Wealden
	Jurassic . . .	Oolites Lias
	Triassic . . .	Rhætic Keuper Muschelkalk Bunter

Palæozoic	Permian . .	Zechstein
		Rothliegendes
	Carboniferous .	Coal Measures
		Millstone Grit
		Carboniferous Limestone Series
	Devonian and Old Red Sandstone	
	Silurian . . .	Ludlow
		Wenlock
		Llandovery
	Ordovician . .	Bala
		Llandeilo
		Arenig
	Cambrian	
	Archæan . .	Gneisses, Schists, etc.

The meaning of the names of the great groups has already been explained, but those applied to the smaller subdivisions are less systematic. Thus the names of the various formations of the Cainozoic group depend upon the proportion of recent to extinct genera. For instance, Eocene, the dawn of recent; Oligocene, few recent; Miocene, less recent (containing a minority of living forms); Pliocene, more recent (containing a majority of living forms); Pleistocene, most recent.

In the Mesozoic the origins are more varied. Thus Cretaceous means chalk-bearing, Jurassic refers to the occurrence of the rocks in the Jura Mountains, and Triassic indicates threefold in allusion to the marked threefold division of the beds of this age in Germany.

The names of the Palæozoic formations are, with the exception of the Carboniferous, derived from the districts where their details were first worked out. Thus Permian from the province of Perm in Russia; Devonian from the county of Devon; Silurian and Ordovician from the districts occupied respectively, at the time of the Roman occupation, by two British tribes, the Silures and the Ordovices; and Cambrian from Cambria or Wales.

Carboniferous means carbon-bearing, and has reference to the fact that most of the coals worked in the British Isles are in that formation.

Of the names of smaller subdivisions some are place-names, some have reference to the nature of the rocks and the uses to which they have been put, *e.g.* Millstone Grit, while yet others are local names in use by farmers and quarrymen and adopted by the earlier geologists.

The fossils which are found in the stratified rocks have been preserved in various ways. In some cases the actual matter of the hard parts of animals, such as shells and bones, has been preserved; in others this has been replaced by another mineral substance, such as silica or carbonate of iron. Sometimes mere casts or impressions bear testimony to the former presence of organisms.

It is not intended to enter into the question of the classification of the animal kingdom in the present work, but it may be well to briefly explain the system of naming animals and plants.

Of course there are, even amongst creatures at present living, far too many different beasts for us to give them all common names, such as cow, cod, or gnat, and indeed many of the names in general use are applied to a large number of different creatures, and are therefore not sufficiently accurate for scientific purposes.

It is found on studying animals, and the same is true of plants, that they fall into groups having many features in common, while nevertheless possessing characters of their own which differentiate them from the other members of the family.

The groups are called genera and the individuals species. Thus the generic name of the cat family is *Felis*, while its different members, such as the lion and the tiger, are designated *Felis leo*, *Felis tigris*, and so on.

In many instances both the generic and specific names are descriptive of the animal, but in others they indicate the place from which they came, the geological formation in which they are found, or the name of their discoverer. As an example of a descriptive name we may take *Pterinopecten papyraceus*, a bivalve shell which is found as a fossil in the Coal Measures. *Pterinopecten* means the winged comb shell, and *papyraceus* indicates the fact that it is paper-like, the rock in which it occurs containing so many shells that it splits up like sheets of paper.

The science of palæontology, which deals with the classification and evolution of fossils, is too vast a subject to be treated of in the present volume, and the various fossils mentioned in the succeeding chapters may be looked upon merely as indicators of the geological formations in which they are found. They are all of common occurrence, and will be found figured or described in any text-book of general geology.

Armed now with the Doctrine of Uniformity and Smith's principle that "rocks may be identified by their fossil contents," let us take the advice of Petrus Severinus, who in 1571 addressed the thinkers of his day as follows: "Buy yourselves stout shoes, get away to the mountains, search the valleys, the deserts, the shores of the sea, and the deepest recesses of the Earth; mark well the distinctions between animals, the differences among plants, the various kinds of minerals, the properties and mode of origin of everything that exists. In this way and no other will you arrive at a knowledge of things and their properties."

PART II.—A GEOLOGICAL RECONNAISSANCE

CHAPTER V

THE COAST-LINE

Having heard rumours of the probable mineral wealth of a country which we will call Geologica, of which little is known geologically, we may imagine that we decided to make an expedition into its interior. This, of course, involved considerable expense, but we hoped to be able to recompense ourselves by the discovery of minerals of economic value. We have endeavoured to find out the structure and history of the land, relying as far as possible on our own observations, but not rejecting the conclusions of others whose work appeared, on comparison with our own observations, to be satisfactory.

There is a good topographical map of the coast region published, and we provided ourselves with several copies of this. It indicates amongst other things the mountains and rivers, giving the heights of the principal summits and showing the general configuration of the country by means of contour lines, *i.e.* lines drawn at equal vertical intervals through all points of the same elevation. The contour lines are drawn at intervals of 250 feet, but there are also two others on the lower parts of the country, one at an elevation of 50 feet and the other at 100 feet above sea-level. The positions of the principal towns and villages, and of such railways and roads as exist, are also indicated, and the north point is shown by means of an arrow.

We chartered a small steamer by means of which we could explore the navigable rivers, and we were informed that it would be possible to obtain small boats and canoes, when we reached the shallower waters farther inland. Horses, men to act as guides, and porters were also available, we learned, should we need to leave the main waterway, or the neighbourhood of the railways.

Before starting we provided ourselves with the tools and apparatus necessary for our work, and these included a supply of picks, shovels, and geological hammers for use in collection of specimens of rocks, minerals, and fossils, which we might wish to bring away with us for further investigation, bags for the carriage and storage of these, and paint for the purpose of numbering the specimens. A magnetic compass for the determination of directions, a clinometer to record inclinations and the dip of the strata, an aneroid barometer to record heights, surveying instruments such as a level and a theodolite, and good field-glasses also formed part of our equipment, in case we should visit the wilder and less perfectly surveyed parts of the country.

Camp equipment, including cooking utensils and a kit of carpenter's and mechanic's tools, had been provided on the steamer, where there was also a microscope and all the apparatus necessary for the preparation of microscope slides, in which one of the members of our party was an expert. We had also with us a palæontologist well versed in matters relating to fossils and their distribution.

We examined the map in order to plan out our first expedition, and chose our route so as to see as much as possible of the country, and to obtain a general idea of the outlines of its geological structure.

One of the most prominent features of the map is the Hutton River, which stretches far away inland, and is navigable for the steamer for upwards of 500 miles. It has also several navigable tributaries and many smaller ones which we shall probably be able to ascend by boats and canoes.

Since transport by water is so much easier and more convenient than by land, the river seems to offer the easiest access to the interior of the country, and it also possesses the advantage of enabling us to see something of the structure of the country in the various gorges and deep valleys which it has cut.

Having arrived at Port Hutton,[1] near the mouth of the river, we decided to spend a few days, while our outfit was being transferred from the liner to our own steamer, in making an investigation of the coast-line in the neighbourhood, as we hoped here to get some idea of the nature of the rocks which form the coastal plain, and of their relation to one another.

Near the mouth of the river the coast was low and sandy, as we had observed from the deck of the liner as we entered the estuary, and as there was the village of Seaview, a small watering-place, only a few miles distant, we arranged to take up our quarters there for a day or two, and spend our time in an investigation of

[1] Refer to maps, Plates XV. and XVI.

the beach deposits and of the line of low cliffs to the east of the town.

On reaching the sea we found that there was a great accumulation of rounded stones forming a shingle beach, and that below this were wide stretches of sand, covered at high tide, but at the time exposed to view as it was dead low water (Plate I.).

The sand was yellow in colour, and consisted chiefly of small grains of quartz, but there were also some grains of a heavy black mineral, which was strongly attracted by a magnet, and this we concluded to be magnetite, an oxide of iron. These grains of magnetite had accumulated in the hollows of the ripple-marks left by the outgoing tide, and were also to be seen in little patches here and there in the courses of the rivulets which were flowing down the sandy shore. They had evidently accumulated in these positions owing to their being heavier than the quartz grains which formed the bulk of the sand, as once they had got into the hollows the feeble currents of water had been unable to move them, although still able to move the lighter grains. The sand also contained numerous broken shells and small white particles, which upon investigation proved to be tiny shell fragments which had been washed up by the waves from some oyster bed or cockle bank farther out to sea.

At the water's edge the sand was much finer than higher up, and it was also somewhat muddy, while the brown colour of the water led us to suppose that a little farther out the bottom consisted of mud.

Returning to the shingle beach, we found that it was arranged in several terraces one above the other, like

PLATE I.—A Shingle Beach.

large steps, and that the uppermost of these consisted of larger boulders than those which constituted the lower ones. This was the storm beach, and was only reached by the water at high tide during storms, when the waves were sufficiently powerful to move the large heavy masses. The lower steps, consisting as they did of smaller, lighter pebbles, were the product of the smaller waves of fine weather, and their arrangement in successive terraces was due to the varying height of the tides. In this particular instance there were two beaches below the storm beach, and these we may call the spring-tide and neap-tide beach respectively.

When a breaking wave has driven the stones up the slope of the beach, the undertow produced by the retreating water carries some of them back again, but as the force of the on-rushing wave is much greater than that of the undertow, the latter is only able to carry back the smaller pebbles and sand, and that is why the shingle always accumulates near high-water mark instead of being distributed all over the shore.

On examination of the materials of the shingle, we found that it consisted for the most part of rounded masses of a heavy dark-gray rock which is called basalt, but there were also some pieces of a white material which could be easily scratched with a knife, and which proved on further examination to be limestone; also numerous pebbles of flint.

These boulders must have been broken away from the cliffs by the waves, and, scrambling over the shingle, we examined the cliffs behind. These we found to vary in height from 10 to 30 feet, and to consist of horizontal beds of brownish clay with three thin layers of yellowish sand—one near the base, another near the middle, and the third capping the higher portions of the cliffs. Clearly the materials of the shingle could not have been derived from these, and we had therefore to look elsewhere for their source. In the meantime, however, we made a further examination of the cliffs of clay and sand, and one of the first things we noticed about them was that both clay and sand contained fossil shells. These were not wholly unlike the shells which we saw on the sandy beach below the shingle, and we made a collection of the fossils for purposes of comparison. They included a cockle, an oyster, a scallop shell, a whelk, and several limpets with curious openings on the top resembling keyholes in form. On comparing these with the shells on the beach, we found that the oysters were precisely similar, but that the cockle from the cliff was more elongated than the one from the beach, and that the scallop and the whelk also differed from the recent specimens, while the limpets from the sand were without the "keyholes," being completely closed as regards their upper surfaces.

On reference to our books we found that the fossil forms belonged to the Pliocene formation, and we therefore concluded that the clays and sands of the cliffs were of that age.

Our map told us that some few miles to the east there was a village called Clifftown, and on looking in that direction we saw, by the aid of our field-glasses, that the coast was high and rocky, and that the seas were breaking far out from the shore in the neighbourhood of a headland which terminated in a bold vertical cliff.

This change in the character of the coast promised something of interest, and we decided to visit Clifftown, finding on inquiry that it was possible and quite safe to proceed along the shore at all states of the tide. For the first mile or two the Pliocene sand and clay continued with little or no change, but just beyond the mouth of a small stream, Dipton Burn, the cliffs rose abruptly to a height of upwards of 100 feet and were seen to consist of a white limestone containing flints similar to those which we had found as boulders in the shingle beach.

The junction of the Pliocene beds with the limestone was obscured by masses of the latter which had fallen from the cliff, and we were in consequence unable to determine the exact relationship of the one to the other.

The stream which we had just crossed entered the sea through a shallow valley excavated in the clays, but as the country appeared to be higher inland, we thought it desirable to follow the valley for a short distance in the hopes of finding a section which showed the contact between the clay and the limestone.

At first we found little of interest, the eastern bank being much higher than the western—in fact, the stream was flowing along the western edge of a range of low hills, which we saw, from numerous small outcrops of the solid rock peeping out amongst the vegetation, to consist of the white limestone.

About half a mile from the coast the valley turned towards the west, leaving the foot of the hills so that there was no object in following it farther. Near this point, however, the stream was joined by a small tributary which flowed down from the hills. This we followed, and at first saw the clay beds exposed on its banks, but at the foot of the hills there was a deeper section, of which Fig. 8 is a sketch.

In the lower part of the stream were the Pliocene beds, and these were seen in the middle of the section to end abruptly against a cliff-like face of the limestone, which dipped at a low angle towards the east.

Along the line of junction was a layer of conglomerate consisting of rounded pebbles of flint embedded in a matrix of Pliocene material which was noticed to become

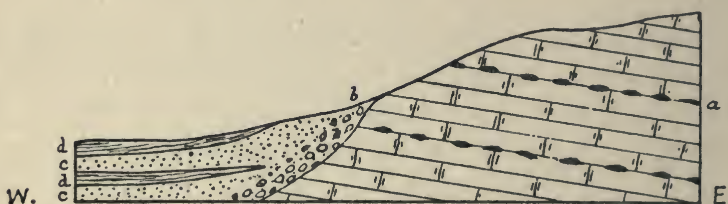

FIG. 8.—Section in tributary of Dipton Burn. *a*, Chalk ; *b*, Conglomerate ; *c*, Pliocene Sand ; *d*, Pliocene Clay.

markedly more sandy in character as the junction with the limestone was approached.

We considered that we might safely interpret this section as showing the old coast-line of the Pliocene sea with its cliffs of older rocks, its shingle beach, and the sandy and muddy deposits which were formed in its shallow waters near the land.

A further examination of the section showed that, while the Pliocene rocks lay in an almost horizontal position, the older limestone on which they rested dipped at an angle of some 15° towards the east, and that the ends of its layers had been broken away before the newer clays and sands were laid upon it. This is the type of junction which is called unconformable, and it indicates a considerable lapse of time, during which denudation took place, between the formation of the two sets of rocks.

We were able to obtain one or two fossils from the limestone, and on returning to the beach a further collection was made from the fallen blocks at the foot of the high limestone cliff. These included a sea-urchin, which was identified as being *Holaster subglobosus*, which is only to be found in the upper part of the Cretaceous formation, and we therefore concluded that we were dealing with the chalk, which was borne out by an examination of the other fossils, which were all of Cretaceous species.

Still travelling eastward along the shore and approaching the rocky headland of Black Point, we noticed that the line of cliffs ran a little way inland, being separated by a narrow terrace some 50 feet above tide-level from the shingle beach below. Several streams had cut shallow trenches in this terrace, and the exposures in their banks showed that it consisted of shingle and sand arranged after the manner of a beach, and containing shells precisely similar to those of the present shore. This deposit was far too high to be reached by the waves of even the greatest storms, and we therefore decided that it belonged to the class of raised beaches, and indicated a recent elevation of the land to the extent of 50 feet.

The raised-beach terrace extended right round the headland, but at, and near, the point it consisted of a rocky platform partly overgrown with mosses and lichens, the upper surface being here also at an elevation of about 50 feet above tide-level. On the outer edge of the terrace we descended a low cliff and found ourselves on a terrace similar in all respects except for the absence of mosses or other vegetation, and showing every indication of having been battered and scoured by the action of the waves, which were even then breaking in sheets of foam on its seaward margin. The rock of these two terraces, the present beach, and the older raised beach was the same gray basalt which constituted the chief part of the shingle at Seaview, and this rocky headland was doubtless the source from which the boulders had been derived (Plate II.).

On returning to the surface of the upper terrace, and crossing it, we found that the lower parts of the great cliff, which consisted of basalt, were penetrated by numerous water-worn caves, giving further evidence that the sea had once reached this level. We retraced our steps a little way in the direction of Seaview, and endeavoured to find the place where the chalk and the basalt came into contact, and, as this would probably be found most easily in the cliffs, we travelled along their base.

A point was soon reached where the junction of the two rocks was well seen, the section being as indicated in Fig. 9.

The chalk to the west was continuous with that at Dipton Burn, and dipped at the same angle, but as it approached the margin of the basalt the bedding planes became ill-defined and the rock became yellowish in colour, until at about 10 feet from the actual junction it consisted of a white crystalline substance, not unlike loaf-sugar in appearance, but more crumbly. So friable was this rock that there was a recess some 20 feet deep in the cliff face at this point, the saccharoid limestone, as the white crystalline variety is called, being softer than either the unaltered limestone or the basalt, and thus wearing away more rapidly under the action of denuding agents.

The basalt, as we knew, was an igneous rock, and the alteration of the chalk along the line of junction was doubtless due to the action of the heat from the basalt, which must have reached its present position in a molten state.

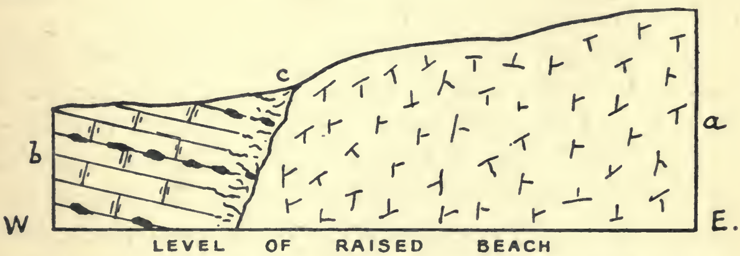

FIG. 9.—Junction of Chalk and Basalt. *a*, Basalt ; *b*, Chalk ; *c*, Altered Chalk on line of contact.

We next proceeded to the end of Black Point and, it being still some time from high water, noticed that the black basaltic rocks of the point ran out for a considerable distance into the sea, forming a dangerous reef over which the current of the incoming tide was rushing with great violence towards Seaview. It was this current, doubtless, which was responsible for the transport of the boulders of basalt in the direction of Seaview, they being then flung up on the beach by the action of the storm waves.

On rounding the point we saw before us a large bay bounded by cliffs, and on the farther side was the fishing village of Clifftown, nestling at the foot of a deep ravine up which ran the road along which our return journey must be taken.

Following the line of cliffs, we found that the basalt came to an end about 100 yards beyond the point, and was replaced by the chalk, which was again saccharoid near the junction.

Many caves had been drilled in the base of the chalk cliffs, and most of these lay on lines of jointing, as the cracks which traverse the rock at right angles to the bedding planes are called.

In one or two instances the waves had drilled tunnels through a small headland, thus forming a natural arch, and in others the crown of such an arch had fallen, leaving its outer buttress standing as a detached pinnacle of rock now surrounded by the rising tide. Stacks of this description were to be seen at intervals all along this part of the coast, and they bore witness to the enormous destruction of the coast-line by the action of the waves (Plate III.).

As we penetrated farther into the bay we found that there was no longer a raised-beach platform such as that on Black Point, but that the shingle beach lay against the foot of the cliff, only the storm beach being now above the water as it was high tide. Travelling over the shingle was somewhat arduous, and we therefore waited for the ebb of the tide, the interval being profitably occupied by an examination of the cliff face.

Near its base the cliff showed many signs of the battering which it had suffered from the shingle being flung against it during storms. The shingle here consisted almost entirely of blocks of chalk and flint, similar to the material of the cliffs, but included a few of basalt, which, however, was finer grained than that of Black Point.

There was a band of this fine-grained basalt running up the cliff in an almost vertical direction. It was about 8 feet in width, and cut through the beds of chalk in a manner similar to that of the larger mass previously seen, while on each side the chalk was saccharoid, but only for a distance of 3 inches from the edge of the basalt.

This basalt had evidently come up from below in a molten condition, and had filled a fissure or crack in the chalk. It was in fact a "dyke," and the larger mass at Black Point appeared to be of a similar nature.

Continuing in the direction of Clifftown, we noticed that the cliff became somewhat lower, and that the dip of the chalk first became less and less and then changed its direction to north-west. It then increased very rapidly until it reached an angle of 70°, which continued to within a short distance of the village. There then appeared beneath the chalk a bed of sandstone of a grayish-green colour, and containing numerous dark-green, almost black when wet, grains of a mineral called glauconite. This sandstone was found to contain numerous well-preserved fossils amongst others the molluscs *Pecten asper* and *Exogyra columba*, both of which are found in the Upper Greensand—a rock which occurs immediately below the chalk in the south of England and other places.

From its position underlying the chalk, and the fossils, which it contained, we concluded that this rock was the Upper Greensand. The village of Clifftown was built upon it, and it formed the bed of the Clifftown Burn. The beds of greensand dipped at the same angle as the chalk which lay upon them, and this junction, unlike that in Dipton Burn, was a conformable one.

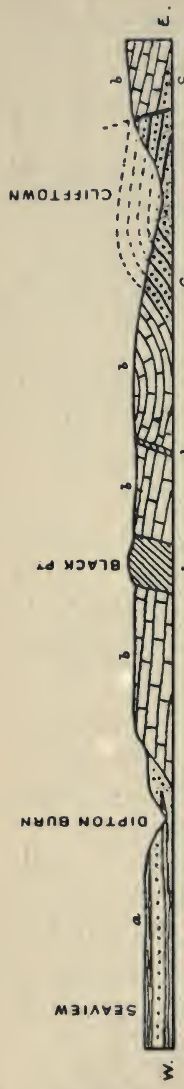

FIG. 10.—Section from Seaview to Clifftown. *a*, Pliocene Sands and Clays; *b*, Chalk; *c*, Greensand; *d*, Basalt.

In the bed of the stream at Clifftown the rocks were nearly horizontal, and a few yards farther on, they were seen to dip towards the east at 15°. This change in the direction of the dip was caused by the occurrence of an arched fold or anticline as indicated in the section (Fig. 10).

A little farther towards the east the chalk again appeared in the cliff, being brought into contact with the greensand along an almost vertical line, which was evidently a fault. There was still a little greensand to be seen at the foot of the cliff, but this soon disappeared below the level of the beach.

Owing to the state of the tide, it was found impracticable to proceed farther to the east, and so a return was made to Clifftown with the object of striking the road back to Seaview.

Before starting on the return journey two small tributaries of Clifftown Burn were visited to seek for evidence of the inland prolongation of the fault seen in the cliffs. It was readily found in the lower stream, the chalk and greensand being seen separated by a narrow band of crushed and polished rock, such as was seen to accompany the fracture in the cliffs below. In the upper tributary the fault, though still observable, was evidently dying out, as the displacement of the rocks was only a few inches.

On the homeward journey the line of the great basalt dyke of Black Point was easily traced, as it formed a prominent ridge on the surface of the land, and had been excavated in several places for road metal.

The line of junction between the chalk and the Pliocene was observed in a chalk-pit near the point where the road to Seaview branched off from the main road to Port Hutton.

We were now in a position to draw a section illustrating the structure of the cliffs from Seaview to Clifftown, and an examination of this served to remind us of the main features of the region (Fig. 10).

Our next expedition was along the beach from Seaview towards the mouth of the estuary of the Hutton River. Here there were no cliffs, but there was a great bank of shingle backed by rows of sand-dunes, some of which reached a height of 60 to 70 feet. These dunes were accumulating under the influence of the wind, which was constantly carrying up sand from the beach and depositing it here.

Some years ago the sand-dunes commenced to travel inland towards Port Hutton, destroying several farms and even threatening the town itself, but the movement has now been stopped by planting starr grass, or "bent," upon the surface of the hills. This grass has long, underground stems, or rhizomes, which are very tough, and which form such a dense tangle that they hold the sand together and prevent its dispersal by the wind. In addition to this, the leaves of the grass, by forming a dense rush-like growth, entrap the flying grains from the beach. Even with this precaution it sometimes happened when there was an exceptionally strong south-east wind that sand accumulated like snowdrifts in the streets of the town, and had to be carted away.

The shingle beach continued westward towards the estuary until it terminated in a point or hook which had considerably constricted the mouth of the river. Early settlers in the country state that this point has grown considerably since their arrival, but that it now seems to be stationary. The shingle travelling westwards under the influence of storm waves and tidal currents has gradually narrowed the mouth of the river, thus increasing the speed of its current, which is now able to carry any additional shingle, which may travel in this direction, out to sea. It was stated that much of this shingle was again flung up by the waves on the opposite coast, and there certainly seemed to be an accumulation of black material along the foot of the sand-dunes. It was, however, too far away for us to ascertain its nature, even with the field-glasses.

Behind our lines of sand-dunes there was a flat area covered with a fine silt which contained, by way of fossils, a few shells of land snails and some leaves and twigs in a partially decomposed condition. This appeared to be a deposit of materials brought down by the river and

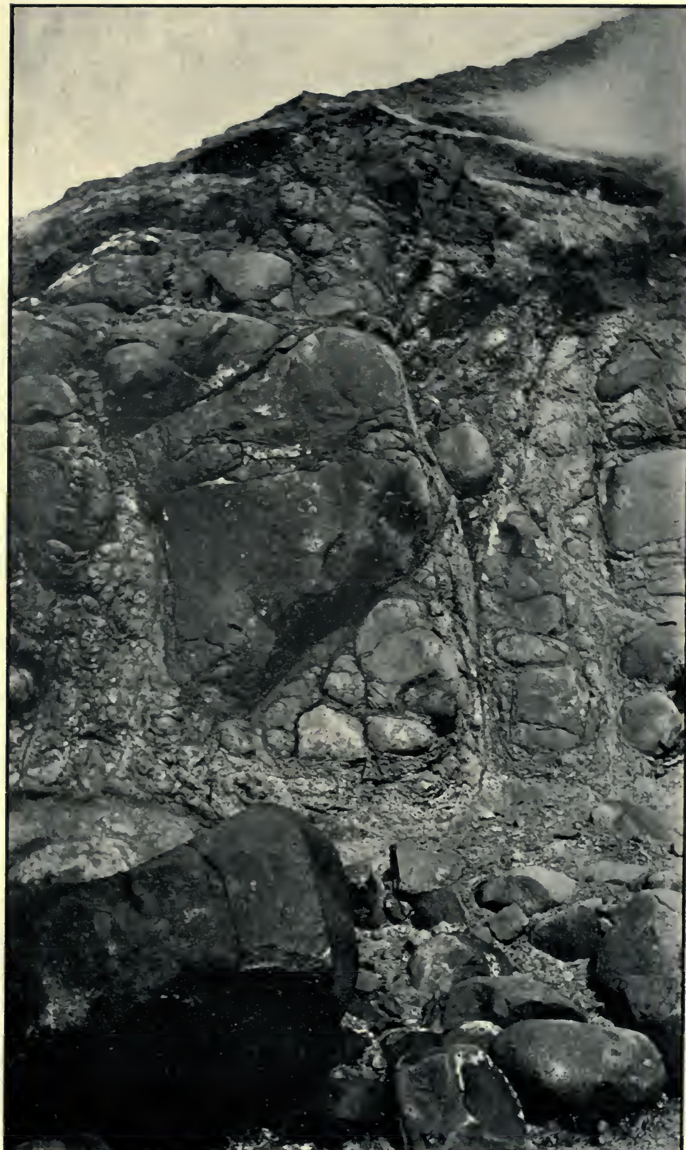

PLATE II.—Basalt near Black Point.

accumulated here in times of flood. We shall doubtless be able to settle this matter after having had an opportunity of comparing the material with the river deposits higher up stream.

The deposit was of no great thickness, as in a heap of material which had been thrown out during the sinking of a shallow well at one of the farms, clay with Pliocene fossils was found, proving that this formation occurred only a few feet below the surface.

On arriving at Seaview we were informed that all was now ready for our trip up the river, so we returned to Port Hutton that evening, and went on board early the following morning so as to take advantage of the flood tide in going up the estuary.

CHAPTER VI

THE RIVER—PORT HUTTON TO SMITHFORD

On reaching the quay at Port Hutton, it was found to be low water, and the extensive mud flats of the estuary were exposed to view. The outlook was dreary in the extreme, the air was cold and damp, and the Sun had not yet broken through the mist which had formed during the night. The mud flats, though at first sight by no means inviting, were far from being without interest.

The source of the mud, and the reason for its deposition in this particular situation, were questions which might well engage our attention. There was a channel running near the centre of the estuary where the water was fairly deep, even in the present state of the tide, and here our steamer lay at anchor. There was a strong current flowing down the channel towards the sea, and this made rowing out from the jetty somewhat arduous. However, having arrived on board, and having stowed away our personal belongings, we spent the time until the turn of the tide in an examination of our surroundings.

The colour of the water flowing down the channel showed that it contained a large amount of mud in suspension, which it was carrying out to sea, and samples of water, collected by means of a bucket thrown over the side, were found to be less salt than the water of the open sea.

It was evident from this that much of the water was derived from the river, but that some part at least was salt water left behind by the tide and now slowly draining from the banks.

The current gradually slackened until it was imperceptible, and then we noticed that the boat was slowly swinging round, and this continued until her bows, which were pointing up stream when we came on board, were directed towards the open sea. The tide now commenced to flow, but the current was not nearly so strong as it was during the ebb. The water was brown and oily looking, and it spread slowly over the mud flats on the sides of the channel. We now got under way, and steamed slowly up the estuary towards the river above. There was little to interest us at first. The distant banks were low, and the country all around was flat; but away to the east we could still see the low rolling hills of chalk in the neighbourhood of Clifftown.

The Sun now broke through the mists, and we got a better view of our surroundings.

The tide continued to rise, but there was no strong current; even such as there was diminished as the time of high water approached. At full tide there was a period of about an hour during which there was practically no movement of the waters. There was scarcely a breath of wind, and had it not been for our back-wash the water would have been without a ripple. After a time the tops of the mud banks appeared, and were at once occupied by gulls and other sea birds, in search of food. The water continued to fall, but still as yet there was no perceptible outward current.

It was doubtless during the period of slack water, before and after high tide, that most of the deposition of mud took place, for about half-ebb the current became so strong and the waters so disturbed that the channel was scoured and kept open. By this time, however, considerable areas of the banks were already dry, and so the film of mud laid down upon them was not removed, and thus film by film the flats were being gradually raised.

The deposition of the mud is largely influenced by the mingling of the fresh and salt water in an estuary. The mud-laden waters of the river, when they mix with the salt tidal waters of the estuary, at once commence to drop their burden of solid particles. For every strength of current there is a certain size of particle which is critical, and any grains which are larger than this are left behind, while any that are smaller are held in suspension and carried away. Two things may influence the deposition. In the first place, if the current is checked, as is that of the river when it enters the wider channels of the estuary, and meets the incoming tide, matter will be deposited. In the second place, anything which tends to increase the size of the particles will bring about a similar result.

If we take two tall glass jars, such as are in use in chemical laboratories for the collection of gases, and fill them, say, two-thirds full of water with which some finely powdered china clay has been mixed, and add to one of them a small quantity of a solution of common salt (sodium chloride), we shall find that the clay soon commences to settle, and after an hour or two the water becomes quite clear, while that in the jar into which no salt was put remains milky, it may be, for several days.

Plate III.—A Sea-stack of Chalk.

If a corresponding amount of magnesium chloride were added in place of the salt, the settling would be found to be still more rapid; in fact it would be complete in about half the time, while an equivalent amount of aluminium chloride would reduce the period to something like one-third of that obtained by the use of the sodium chloride.

The chemical composition of sodium chloride is NaCl, where Na represents an atom of sodium and Cl an atom of chlorine. Magnesium chloride is represented by the formula $MgCl_2$, while that for aluminium chloride is $AlCl_3$. From this we see that an atom of sodium is only capable of combining with one atom of chlorine, whereas an atom of magnesium can take up two, and an atom of aluminium three. It would appear, therefore, that there is some connection between the "Valency," as this property of uniting with atoms of another element is called, and the effect produced upon the particles of mud in suspension in the water. Aluminium which is tri-valent produces three times, and magnesium which is di-valent, twice, the effect of the mono-valent sodium.

It is known that in dilute solution these substances all split up into bodies called ions, which are believed to carry charges of electricity proportional to their valency. Some electric effect would appear to be produced on the mud particles, which causes several of them to draw together and form a single particle, which, owing to its greater size, falls to the bottom. This is more or less supposition, but the fact that the precipitating effect of the three substances is proportional to the valency of the metals which they contain lends strong support to the belief.

Whatever may be the explanation ultimately adopted, there is experimental proof that sodium chloride and magnesium chloride, both of which are present in sea water, do produce a flocculation and a consequent precipitation of tiny mud particles suspended in water, and this action undoubtedly accounts for the deposition in estuaries of a large quantity of mud and silt which would otherwise be carried out to sea. It is of interest in this connection to note that compounds of aluminium, such as ordinary alum, are of use to purify water from suspended matter so as to render it fit for drinking or other purposes.

On arriving near the head of the estuary, we saw that it narrowed rapidly, and we soon found ourselves sailing up the river, between high banks of silt, covered with grass and other dwarf vegetation, which prevented our getting a view of the country from the deck of the steamer.

Along the banks were a few farmhouses surrounded by poplar trees, and here and there a windmill of the modern circular type, such as was often used at home for the purpose of pumping water.

Houses, windmills, and trees all appeared to rise from land some feet lower than the river banks, and on ascending an iron ladder attached to one of our funnels we saw that this was indeed the case.

On first thoughts, it would seem that the embankments on the sides of the river had been constructed by man to prevent the overflow of the waters on to the low-lying country beyond. The embankments, however, appeared to be of great size and thickness, and showed no signs of recent work having been done upon them, and, furthermore, the country was still but sparsely inhabited, and it would have been a Herculean task for the few farmers who dwelt along the river's banks to accomplish so great a work.

The banks and the presence of such a large number of windmills aroused our curiosity, and we determined to land at the first suitable spot to investigate these matters. A few miles farther up stream we noticed a wooden jetty, and gave instructions to put the steamer alongside.

On landing we found that our impression that the banks were far too large to be artificial was fully justified. They were 40 or 50 feet in thickness, and 10 or 12 in height above the country beyond, which was flat and intersected by numerous artificial canals of varying size and at two different levels. The smaller and more numerous canals were on the general level of the ground, but there were two larger ones, which ran at right angles to the course of the river, and had been built up to such a level that their waters could be discharged into it at low tide. The windmills were attached to pumps which lifted the water from the low-level canals into the high-level ones, so that when the tide fell, and the sluices were opened, it might flow away towards the sea. Here we had a system of drainage not unlike that which is in use in Holland and in the fenlands of the east of England.

Much of the country beyond the raised river banks was below the level of the waters of the stream, when the tide was at the full, and doubtless when high spring tides coincided with heavy rains, disastrous floods would occur. The deposit of which this part of the country consisted was very porous, and it was only by means of the somewhat elaborate system of drainage channels and pumps that it could be rendered fit for cultivation, as even in the absence of floods much water percolated through from the bed of the river.

When drained, however, it fully repaid the outlay, as it was extremely fertile and even in the driest season never suffered from want of moisture.

The farmer to whom the jetty belonged told us that there had been several disastrous floods owing to the waters of the river breaking through weak places in the banks, and he had almost decided to give up his homestead and land, which he had rendered fruitful by such heavy toil, and to start afresh at some more favoured locality farther inland, when the Government came to the rescue and repaired the broken banks, strengthened weak places, and appointed an inspecting engineer and a staff of labourers to keep the embankments in repair.

He further informed us that the opposite bank was still uncultivated, and that there we could see the country in its primitive condition.

Before going on board again we visited a new drainage canal which was in process of excavation, so as to obtain some idea of the nature of the materials of which the land consisted. The cutting was some 10 feet deep, and was excavated in fine sand and silt, with a few layers of gravel, consisting of small rounded pebbles, with a layer of finer material of a muddy character at the top. These were all clearly river-borne sediments, and it was evident that we were dealing with the "alluvium" of a flood-plain.

In the materials which had been thrown out of the excavation, we found some bones and teeth of a deer, a wild pig, and a wolf, all of which are living in the country at the present time. From this it was evident that we were dealing with a recent deposit.

Reaching the opposite bank by means of our ship's boat, there being no suitable landing for the steamer, we proceeded to investigate the undrained land, and found it to consist of marshy and swampy ground covered with reeds and rushes and other aquatic and semi-aquatic plants.

Here there were several breaches in the banks, and in one of them we were able to see a section of the embankment. It consisted of materials similar to those seen in the upper part of the drainage channel section, namely, the finer silts and muds, but strongly bound together by interlacing roots and stems of plants similar to those growing on its upper surface.

The manner in which these natural embankments are formed is somewhat as follows: The mud-laden waters of the river overflow the banks during wet seasons, inundating the surrounding country, and convert it for the time being into an inland sea. Then as the water flows out from the river-course, its velocity is checked by the resistance of the rank vegetation on the margins, and much of its burden of solid particles is deposited. The waters, thus partially clarified, pass outwards over the flood plain, where they deposit the remainder of their load.

In this way the whole surface of the area is slowly raised, but since the greater amount of the sediment falls close to the side of the river, this part is raised more rapidly than the remainder, and thus the embankments are produced.

Navigation now became more difficult as the river commenced to wind greatly, swinging now to right and now to left in great loops in which there were many shoals. These shoals consisted of masses of water-worn gravel, and they always occurred on the inner sides of the bends, while the deep water, accompanied by a steep bank, was found on the outside of the curve. It was now necessary to tie up the steamer for the night as it was not safe to attempt to pass through this section after dark.

The meanders of a river are due to some obstacle,

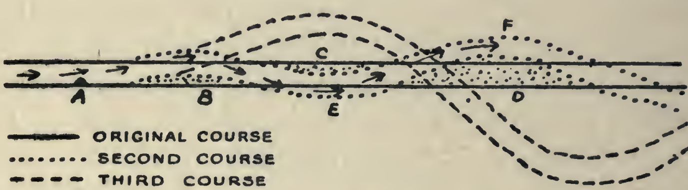

FIG. 11.—Diagram to illustrate the development of meanders.

such as a large boulder or a fallen tree interfering with the flow of the water as seen in Fig. 11. An obstacle being introduced at A, the stream is thrown across to the opposite bank, as indicated by the arrows, and at once commences to cut away the soft alluvial deposits forming an embayment. The stream passing round this curve is projected on to the other bank, which it treats in similar fashion. In the meantime the current at B, behind the obstruction, will be but slight, and here sand and gravel will commence to accumulate, thus forming a gravel bank such as we have already encountered. An examination of the arrows, which indicate the direction of the current, will make it clear that matter will also be deposited at C and D, while excavation will be the rule at E and F.

Once a set of windings is established, and a surprisingly small obstacle will suffice for its initiation, it tends to increase in amplitude, and the individual bends move steadily down the valley towards the sea. The dotted lines in the diagram indicate a further development of the meanders, indicated by the continuous lines.

On landing here for an evening stroll, the country was seen to be much less swampy, and the river banks less elevated than was the case below. Here and there were swamps with many wild fowl, while about a mile away was what appeared to be a lake, and from this came a constant clamouring of wild duck. It would probably repay the trouble of an examination, but this had perforce to be deferred until the morrow, as the light was fast failing us.

Wild Duck Lake lies in the grassy plain, and its form is that of a horseshoe, with its open end towards the river, from which it is separated by a distance of about a quarter of a mile. On traversing the piece of land between the two arms of the lake it was found to be generally level and finally to dip beneath the waters in the form of a sandy beach, while the outer bank had a more abrupt slope, surmounted by an embankment similar in size and form to that which bordered the river.

The width of the lake was similar to that of the river, and its two arms were continued in the direction of the stream as bands of marshy swamp.

There was no doubt in our minds that the lake had once formed part of the river bed, that it was in point of fact a loop of the stream, which had been cut off by the breaking down of an isthmus, such as that we see on the map midway between Wild Duck Lake and Smithford.

Once the main current of the river was diverted from the loop the portions of its channel near the river would soon become blocked up by the detritus swept in by such water as still flowed through it. Thus it became a lake, and as this part of the plain is still flooded occasionally it will eventually be filled in and become a curved swamp, like numerous others which lie dotted over the alluvial flats on both sides of the river.

At Horseshoe Bend is the almost complete loop which has already been noticed on the map, and on arrival at the narrow neck of land which alone remains between its two ends, we found that engineering works were in progress, and learnt that a canal was being cut through the isthmus with the object of shortening the journey to Smithford.

We decided to land here and walk across the isthmus, while the steamer went round the loop, so that we might have an opportunity of examining the section exposed in the canal trench. Here we saw that the material of the flood plain, to a depth of 30 feet, the limit of the excavation, consisted of material similar to that which was exposed in the drainage channel lower down the river, but here there was rather more gravel, and the silt was perhaps a little coarser.

The stratification of the deposit was by no means simple; the beds were often wedge-shaped and sometimes lenticular, sand, gravel, and fine silt alternating frequently after the manner indicated in Fig. 12. This type of stratification is called current-bedding, and the confusion of the layers is due to the ever-changing direction of the currents of the river, in which the alluvium was deposited.

Close to the surface of the ground the deposit became much more regular and, except where the bedding had been obliterated by the action of roots and surface weathering, the layers were horizontal. The material in this upper part of the section was very fine-grained and appeared to be the mud deposited by the

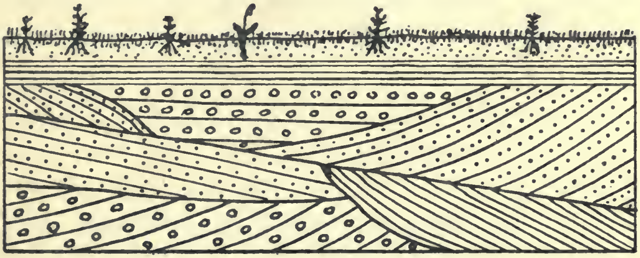

FIG. 12.—Section in Alluvium showing current-bedding.

waters of successive floods, as they spread out over the alluvial flats.

The pebbles in the gravels were of several different kinds of material. The greatest proportion was of white or pale-yellow quartz, but hard bluish grits, gray and cream-coloured limestones, brown ironstone and some fragments of granite and other igneous rocks were also present. As in all probability the whole of the material had been brought down the valley by the river, we thought it probable that we should find all these rocks *in situ* in some part of the river bed or in those of its tributaries.

Smithford, which stands at the junction of East River with the main stream, was an early settlement and was originally established at the ford over the tributary stream, which is now replaced by a road and railway bridge. It owes its present importance to the extreme richness of the soil in its neighbourhood, and the consequent flourishing condition of agriculture. This great fertility is doubtless due to the materials brought down by the river and originally derived from the waste of many different kinds of rock in various parts of its drainage basin. The diversity of the parent rocks, as regards chemical composition, ensures the presence of all the substances necessary for plant life, which might not be the case with the alluvium of a stream draining but a single kind of rock.

A journey up East River might furnish us with an opportunity of examining the inland extension of the rocks already studied on the coast between Seaview and Clifftown, and with this object in view we made a few days' stay in the Smithford district.

For some distance the character of the tributary stream was similar to that of the main Hutton River, and our journey being necessarily slow—as there was insufficient water for the steamer and we had, in consequence, to use boats—became somewhat tedious.

At the junction of the two streams we decided to explore the one which flowed in from the south-east, and as this was navigable with difficulty even by small boats, we obtained horses at a farm and rode up the valley. This was shallow and the surrounding district devoid of any marked features, a low rolling country, for the most part covered with trees.

PLATE IV.—(*a*) Wind-worn Chalk.

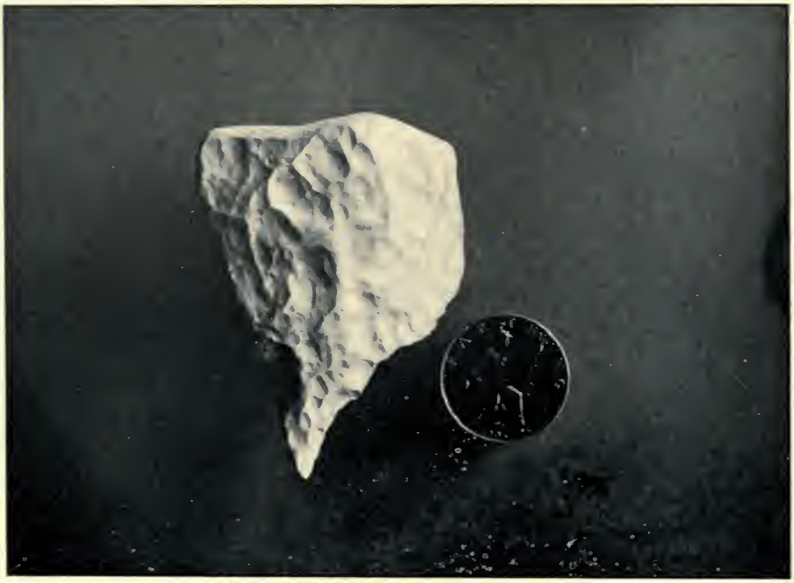

PLATE IV.—(*b*) Wind-worn Chalk.

A day's journey brought us to what we believed should be the line of the great Black Point dyke. About this point the alluvial flat came to an end, and the stream flowed in a V-shaped valley cut in a brown clay which was well exposed at frequent intervals. No signs of the dyke or of the chalk were to be seen, however; furthermore, pebbles of basalt and flint were absent from the bed of the stream.

Through a clearing away to the right we could see that the land rose more rapidly, and on the slope of the hills we found some pebbles of basalt; a little farther up we came upon the heading of a deserted mine which had been driven into the hillside in search of metallic ores. Judging from the materials of the tip-heap, the search had proved fruitless,

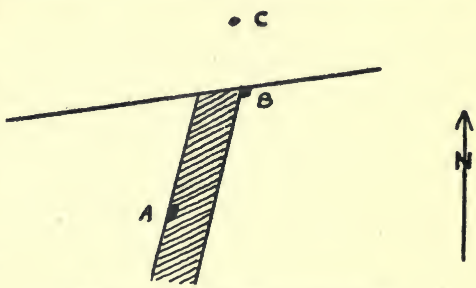

FIG. 13.—Plan of old workings.

but other similar excavations in the immediate neighbourhood gave us the key to the geological structure. These were in the relative positions indicated by A B and C in Fig. 13. A was a heading driven along the side of the basalt dyke, and one side of it was in chalk; B was a small pit some 10 feet deep, cut in the chalk but showing the basalt in its western wall, and a thin layer of brown clay capping the section on its northern side. The clay was seen to overlie both the chalk and the basalt in this section. At C there was a shaft which with some difficulty we descended, to encounter, at a depth of 30 feet, a floor of basalt, the upper part of the shaft being in the brown clay, with a thin bed of rolled flints at its junction with the basalt. On returning to the surface we found that the heap of clay thrown out from the shaft had been disintegrated by the weather, and that it contained numerous fossils similar to those which occur in the lower subdivisions of the Eocene Series, and we therefore concluded that there was here an unconformity between the Eocene and the Chalk below, and interpreted an east and west section through C as follows (Fig. 14).

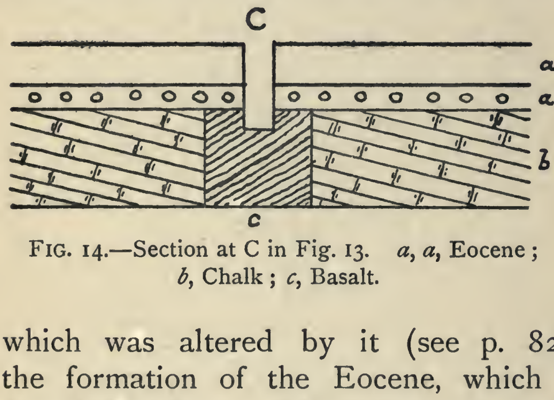

FIG. 14.—Section at C in Fig. 13. *a*, *a*, Eocene; *b*, Chalk; *c*, Basalt.

This gave us a date for the formation of the dyke, which was evidently subsequent to the formation through which it cut, and which was altered by it (see p. 82), but prior to the formation of the Eocene, which rested upon its denuded surface. This latter view was confirmed by the occurrence of a few pebbles of the basalt amongst the rolled flints at the base of the Eocene in another section close by.

On returning to the stream and again examining the brown clay in its banks, a few fragmentary fossils were unearthed, and these were found to belong to the same Eocene genera as those near the dyke.

Returning to the fork we rejoined our boats and proceeded up the main branch of the East River as far as the depth of water would allow. Arrived at a point which should, in our opinion, lie on the line of the Black Point dyke, we pitched our camp by the side of the stream as, no horses being here available, we should have to make our exploration on foot, which might take us several days. After a day's march through the forest, over slightly rising ground, we again saw rolling hills before us, and on reaching these, found them to consist of chalk, as on the other side of the valley, but now dipping to the south at an angle of 5°. We were not long in picking up the line of the dyke, as it here

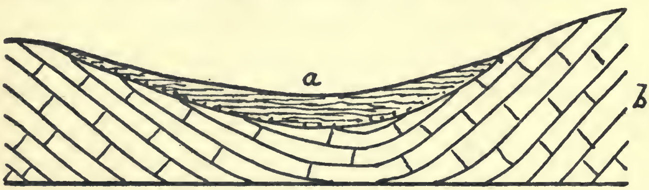

FIG. 15.—Section across the valley of East River.
a, Eocene ; *b*, Chalk.

formed a conspicuous feature in the landscape, standing up as a wall some 25 feet high.

Brown clay in horizontal layers was seen in a small excavation, for here, too, a search had been made for minerals along the sides of the dyke, and a few Eocene fossils occurred.

Our interpretation of the structure of the East River Valley to the west of the dyke is indicated in Fig. 15.

A valley originally excavated in the chalk, which had been previously folded into a gentle syncline, was filled with the deposits of the Eocene sea. These deposits, much softer than the neighbouring chalk, were then brought once more above the level of the sea, and their denudation by the East River and its tributaries is now in progress.

After collecting specimens of basalt from the dyke, and as many of the fossils as we could find, we returned to our camp by the river and dropped down the stream to Smithford, where we rested for a few days before resuming our journey up the Hutton River. The time was profitably spent in getting our floating laboratory into working order and examining and numbering the specimens which we had collected.

The basalt is a very fine-grained rock, and it is impossible to determine its constituent minerals even with the aid of a pocket lens. This being the case we may proceed to prepare a thin section for examination under the microscope. This is done as follows. First strike off with a hammer as thin a flake as possible, and then rub one side of this on a zinc plate with coarse emery powder until it is quite flat. Now polish this flattened surface on another zinc plate charged with fine emery, and finally on a piece of wash-leather stretched on a board and covered with putty powder or jeweller's rouge.

The specimen must now be cemented by its polished surface to a glass microscope slide (usually 3×1 inches) by means of Canada balsam, which is a transparent cement. When this has become hard, the other surface is first flattened, then ground so thin that light begins to show through it.

Great care must now be taken, as the thin slice is very fragile, and it must be slowly rubbed down on the plate with fine emery and finally polished on the wash-leather. It should now allow light to pass freely, and if it does so is ready for mounting.

For this purpose a thin layer of Canada balsam is spread over the section and a thin cover glass placed above. It is now ready for examination.

The frontispiece shows the appearance of our section under the microscope, and it is seen to consist of small grains of a dark gray opaque substance (Magnetite); some crystals and grains of a pinkish mineral, showing numerous parallel cracks in two sets, which intersect each other at a little less than 90° (Augite), and other crystals which are colourless but slightly cloudy in appearance, and of lath-shaped outline (Plagioclase Felspar). In addition to the above there is a grayish-brown substance which fills up the spaces forming a sort of ground-mass or matrix, and which proves, on optical examination, to be glass, while there is also some olivine.

Thus we find that the basalt consists of a granular aggregate of Magnetite, Augite, Olivine, and Felspar, with some glass in the spaces between the crystals.

CHAPTER VII

THE RIVER—SMITHFORD TO LYELL

STARTING out from Smithford and sailing up the river several bends were passed, the appearance of which was much like that of those below the town. The character of the scenery, too, was unchanged. A flat alluvial plain bounded the river on either hand, and there were the usual low embankments bordering the stream.

It was soon noticed, however, that the current had become stronger, and at the same time the course of the river less sinuous. The banks became higher, and were seen to consist of yellow sand. Farms were fewer and more scattered, and had a less prosperous appearance; eventually cultivation gave place to a rank growth of coarse grass, and this again to clumps of whins.

Later on we reached a district almost devoid of vegetation, bent grass and a few thistles being the only flora. Here we effected a landing and found that we were on a wide-spreading cone or fan of sand, sloping towards the south, and having its apex at a point where the river issued from a range of hills which could be seen to the north, stretching from west to east, and apparently closing in the head of the valley.

Here and there, over the surface of the country, we saw lines of low sand-dunes, not unlike those we had examined in the neighbourhood of Seaview. In front of us, as we faced towards the north, we saw that the hills rose somewhat abruptly from this sea of sand, and the white appearance of their rocks led us to suppose that they consisted of chalk.

On a nearer approach this proved to be the case, and the surface of the chalk was found to be curiously grooved and polished (Plate IV.), and even the hard flint nodules which it contained possessed a peculiar glazed surface, all their sharp angles having been rounded off.

There was a strong wind blowing from the south-west, and clouds of sand were flying before it, making travelling very unpleasant. We saw that the grains of sand were being hurled by the wind against the surface of the chalk, and doubtless it was to this action that the polishing of the surface was due.

The few loose stones which were lying in the sand had acquired a glaze similar to that on the chalk surfaces, and here and there streams of sand grains could be seen travelling up deep grooves in the latter, polishing the sides as they went.

Having made our way back to the river, we again steamed up-stream until we reached the foot of the range of hills. Here we found that the valley narrowed suddenly, and that its banks became precipitous. The river now ran in a straight course, and was very rapid, and here and there flecks of foam were to be seen upon its surface.

The floor of the valley to our right was sufficiently wide to allow of the passage of a road between the river and the cliff, but the railway had been carried through a tunnel.

We were informed that the navigation of this part of the river was slow and difficult, as there were dangerous rapids to be negotiated, and, as the steep sides of the valley gave promise of clear exposures of the strata, we decided to go on foot, rejoining the steamer above the gorge. There was no need for us to hurry, as it would be necessary to replenish the supply of coal at the town of Red River, and as we were told that there were several villages where we could obtain food and lodging *en route*, there was no necessity to encumber ourselves with any baggage beyond our hammers and instruments, but as we should possibly collect numerous specimens, we took one of our men to act as porter.

On entering the valley we found that it was even more narrow and gorge-like than we had supposed, and it was the sudden check in the velocity of the stream, on emerging to the more open country below, that had given rise to the great deposits of sand which we had examined on the previous day.

At first the sides of the valley were not very high, and were seen to consist of chalk, with a few nodules of flint, dipping to the south at an angle of 5°. Many of the flint nodules were hollow and contained a white powdery substance, which, from an examination with a pocket lens, appeared to contain minute fossils. As much as possible of this material was collected for subsequent examination.

A mile farther up, the cliffs reached an altitude of 80 feet, and at their base a bed of reddish sand cropped out beneath the chalk. In this we found numerous fossils, including *Pecten asper* and *Exogyra columba*,

PLATE V.—Section in Permian Limestone.

both of which we had previously found in the Upper Greensand which occupied a similar position beneath the chalk at Clifftown on the coast.

At Clifftown the Greensand was of a grayish-green colour, and contained grains of dark-green glauconite, but here it was distinctly red, owing, as we saw on closer examination, to numerous bright red particles, and also to thin films of red matter between the sand grains.

The difference in colour was due to the oxidation of the glauconite and its consequent decomposition, one of the products being a red oxide of iron.

Beneath the Upper Greensand lay a bed of bluish clay of a peculiarly smooth and buttery character. It contained numerous fossils in a very perfect state of preservation, many of them still possessing the beautiful mother-of-pearl lustre which characterised the shells of the animals when living.

Conspicuous amongst these fossils were certain shells which were coiled in a flat spiral, and which, when broken open, were seen to consist of a number of chambers like those of a recent *Nautilus*. These were ammonites, and the two most commonly occurring in the blue clay were *Hoplites splendens* and *Hoplites lautus*, from which we concluded that the rock was the Gault.

Below the Gault, and also dipping at about 5°, was another bed of sandstone not unlike the Upper Greensand in appearance. It was generally of a greenish colour, but there were also a few beds of pure white sand. The fossils, however, were unlike those of the Upper Greensand, the most common being a large oyster-like shell, *Exogyra sinuata*, known to be characteristic of the Lower Greensand. The white and yellow sandy layers contained numerous fossil sponges, and as the white sand presented a peculiar glistening appearance, we took some of it with us for microscopic examination.

At the base of the Lower Greensand was a thin layer of conglomerate, the pebbles in which were small and well-rounded and consisted of white quartz.

Below this there was a sudden and complete change in the colour of the rocks, and also in their angle of dip which, though still in the same direction, changed suddenly from 5° to 30° (see Fig. 16).

The material below the conglomerate was a bright red sandstone which showed current-bedding in a marked

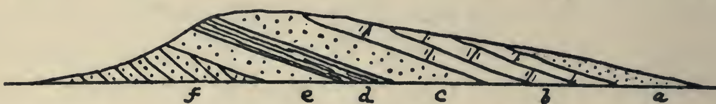

FIG. 16.—*a*, Sand; *b*, Chalk; *c*, Upper Greensand; *d*, Gault; *e*, Lower Greensand; *f*, Trias.

degree, and on closer examination was found to consist of grains of sand as round as millet seed, and sorted out into layers of equal sizes. A prolonged search failed to reveal any traces of fossils in these red beds. The section through the gorge is seen in Fig. 16.

Not far from the upper surface of the red sandstone was a layer containing pebbles of quartz, and some of these had a curious triangular section, and possessed a glaze similar to that which was being produced by the wind-blown sand on the surface of the chalk at the foot of the gorge. Some twenty or thirty of the pebbles were collected, and small boxes were filled with sand grains from the different layers.

Sand was also collected from the beds of Greensand above and added to the stock of material for examination in the laboratory.

Continuing our journey towards the north, the valley soon commenced to widen, the hills falling back on either hand until, arrived at the town of Red River, we found ourselves in the centre of an alluvial flat not dissimilar from that at Smithford.

Looking back towards the gorge, we saw stretched right and left, as far as the eye could reach, a long escarpment or range of hills with a steep scarp face, through which the gorge that we had just left was the only visible opening.

Once more in the laboratory we proceeded to unpack our collections, and found ourselves possessed of numerous fossils from the Chalk, Upper Greensand, Gault, and Lower Greensand, hollow flints from the Chalk and a quantity of the powdery matter from the cavities in their interiors, specimens of the various rocks encountered, including white sand from the Lower Greensand and several boxes of grains from the red beds together with a bag of pebbles from the same source.

All the above we carefully numbered and made a record of the formation from which they had been collected, the exact locality, and the conditions under which they had been found.

As some of the materials of the upper beds may have been derived from the lower ones, we examined the latter first so as to become thoroughly familiar with their appearance in order that, should we encounter them in the newer deposits, we should be able to recognize them.

There could be little doubt that the glaze on the pebbles from the red beds had been produced by the action of wind-blown sand, and as they occurred not only upon the surface of the ground, but also deep within the rock, the polishing could not have been effected in recent times. We concluded, therefore, that the materials of the rock itself must have been accumulated by the action of wind in some ancient desert. The curious three-keeled stones we recognized as similar to the "dreikante" figured in our text-books as occurring in deserts and produced from ordinary pebbles by the sand blast.

The red sand grains suggested rounded particles of oxide of iron, and in order to determine if this were their nature we boiled some of them in acid and applied the usual tests.

On boiling the red grains with dilute hydrochloric acid the liquid rapidly became of a deep orange colour, but it was found that the greater proportion of the sand was left as an insoluble residue. On washing and examining the residue it was found to consist of remarkably well-rounded grains of quartz, all having, in a marked degree, the glaze so characteristic of the *dreikante* and other pebbles. The solution was found to contain ferric chloride, and from this it was concluded that the red coating or pelicle of the sand grains consisted of ferric oxide.

The roundness and desert glaze of the sand grains proved that they had been accumulated in an arid region by the action of the wind, the further fact that they were graded in layers of different sizes supporting this view.

When the wind is blowing strongly it will carry with it grains of all sizes up to the maximum which a wind of its particular velocity is capable of moving, and then as the breeze subsides the coarser grains will be dropped first and form a layer, after which finer and finer layers will be formed as the disturbance slowly subsides.

It seemed to be of interest to compare the red grains observed in the Upper Greensand, and for this purpose a number were picked out by hand from a crushed mass of the rock. On being treated with hydrochloric acid these were found to dissolve completely and to consist entirely of oxide of iron; our original view that they represented grains of glauconite which had become oxidized would, therefore, appear to be correct.

The white sand from the Lower Greensand was found on examination with the microscope to consist largely of the small siliceous spicules which occur embedded in the living tissues of sponges.

We next turned our attention to the contents of the hollow flints. On carefully washing these in running water much of the fine dusty matter was removed, and there remained a small heap of chalk granules, some about the size of an ordinary pin's head and some smaller. On applying the microscope we found the granules to be minute shells of animals belonging to the group of the Foraminifera, and amongst others the genus *Globigerina* was recognized. These minute shells are at present forming chalky deposits on the floors of our great oceans beyond the limits reached by the sand and mud derived from the waste of the land, and as similar shells were to be seen in thin sections of the chalk, it seemed not unreasonable to conclude that we were here dealing with a fossil ooze of which the globigerina ooze is the Recent representative.

The mineral glauconite has been found to occur in the deposits forming on the ocean floor near the edge of a continental shelf, and it would therefore appear that the Cretaceous rocks (Lower Greensand to Chalk) in our section had been formed under the following conditions: the bed of pebbles at the base of the Lower Greensand represents shore conditions, and the Lower Greensand itself, with its glauconite grains and sponge spicules, a greater degree of submergence. The finer sediments of the Gault indicate the mud zone, and the Upper Greensand a temporary return to shallower water, followed by a subsidence of some considerable magnitude during which the chalk was laid down.

The principal trade of Red River appeared to be in bricks and tiles, but there were also large heaps of alabaster and numerous barrels of plaster of Paris lying upon the wharves. These, we were informed, were brought down by a mineral railway from a factory to the north-east, and by the courtesy of the manager we were allowed to travel in one of the empty waggons returning from the town.

Arrived at the works, we found an enormous excavation in a red clay or marl which dipped towards the south at an angle of 10°. At the south side of the excavation the marl was cut off by an east and west fault. Beyond this fault was a red sandstone, which on examination proved to be the same as that which lies beneath the Lower Greensand at the head of the gorge.

We were told that in a bore-hole put down with the object of testing the depth of the marl, the red sandstone was reached at a depth of 150 feet, and a supply of good water, sufficient for the purposes of the works, was obtained from this. Other trial holes showed that the marl diminished in thickness towards the north, and a small cutting at *x* (Fig. 17) exposed the junction with the underlying sandstone. Fig. 17 shows the relations of the beds to one another.

The red marl contained numerous thin layers of gypsum, which is a hydrous sulphate of calcium ($CaSO_4.2H_2O$), and one thick bed of the compact variety known as alabaster. The marl was used for the manufac-

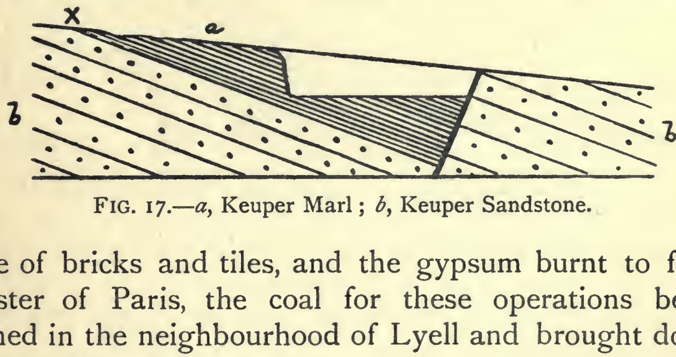

FIG. 17.—*a*, Keuper Marl ; *b*, Keuper Sandstone.

ture of bricks and tiles, and the gypsum burnt to form plaster of Paris, the coal for these operations being mined in the neighbourhood of Lyell and brought down to Red River by barges.

The red sandstone with its overlying deposit of red marl constitute the two divisions of the Keuper, the upper part of the Triassic Formation, and are known as the Keuper Sandstone and Keuper Marls respectively.

While at the brickworks we were told that there was a very fine waterfall on the Red River, and we decided to visit this as it appeared, from the description given us, to lie upon the line of the Black Point Dyke. It was a good day's journey through the forest, but, as there had been a forest fire here about three years previously, it was not very difficult to make our way across.

Arrived at the fall, we found that, as we suspected, it was caused by the Black Point Dyke, the waters of the Red River having been unable to cut through the hard basalt as rapidly as through the soft red sandstone by which it was flanked. The fall was approached from below by a short gorge, the lower part of which was cut in sandstone, but the fall itself was over the dyke, though the waters had already cut part way through it.

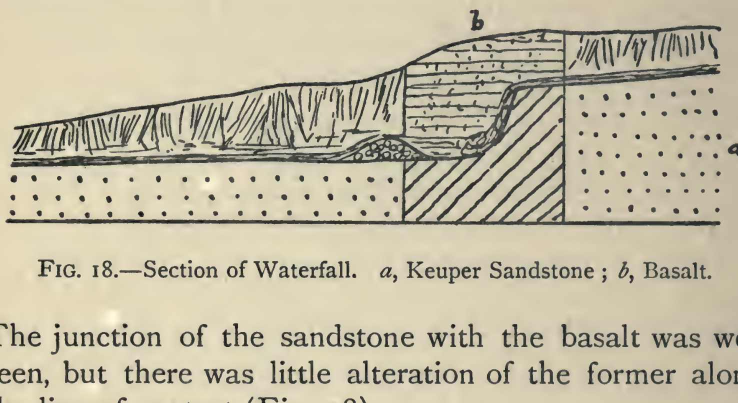

FIG. 18.—Section of Waterfall. *a*, Keuper Sandstone ; *b*, Basalt.

The junction of the sandstone with the basalt was well seen, but there was little alteration of the former along the line of contact (Fig. 18).

At the foot of the fall was a deep pool into which the waters fell, and whose lower lip was formed by a bar consisting of large boulders of basalt, which had been broken away from the dyke and piled up by the action of the plunging water.

An old mineral prospector, now in the employ of the Brick Company, informed us that the exposures of the Keuper Marls were much more extensive on the farther side of the Hutton River, and a visit to this region proved this to be the fact. On the west bank we found the marl to contain numerous casts of small cube-shaped crystals with somewhat depressed faces. These we were able to recognize as pseudomorphs of salt crystals, and the occurrence of several small springs of salt water led us to suppose that it might be worth our while to sink a bore-hole in this neighbourhood in search of rock salt.

With the object of obtaining the necessary apparatus and labour, we returned to Red River *en route* for Lyell, having made arrangements with the prospector to take charge of the work when the boring tackle should have been procured.

After two weeks' hard travelling on horseback and on foot we were not sorry to return to the steamer and to sail leisurely up the winding river towards Lyell. For the greater part of the journey there was little to interest us. Alluvial flats stretched for long distances on either side of the river, and the high banks prevented us getting any good view of the surrounding country.

About a day's sail from Lyell, the valley rapidly narrowed, and we once more entered a gorge, this time so narrow that there was barely room for the road beside the river. Bluffs of Keuper Sandstone guarded the entrance to the gorge, which was, however, for the most part, cut in a cream-coloured limestone of spongy texture which supported an extremely luxuriant vegetation.

Here and there in the precipitous cliffs were thin beds of red and brown marls, but the bulk of the material was the cream-coloured limestone which was often weathered into fantastic forms. On the side of the river remote from the road the cliff passed straight down into the water as seen in Plate V.

The limestone appeared, at first sight, to be devoid of fossils, but a careful search revealed a thin band near the bottom of the cliff that contained numerous though small fossils. These turned out to belong to the Permian genus *Bakewellia*, and resembled somewhat a small mussel shell in form. We therefore concluded that these limestones were of Permian age, which was borne out by the fact that they dipped below the Triassic Sandstone at the foot of the gorge. The gorge itself terminated abruptly, and we found ourselves in Lyell, the capital of the country. The city is built on both sides of the river, and is sheltered by the bold escarpment of the Permian.

Lyell lies at the head of the steamer navigation, and therefore any further exploration of the river would have to be carried out in small boats. As the autumn season was now far advanced we deemed it advisable to defer our start until the early spring, so that we might have the best of the weather for the exploration of the mountainous regions which lay in the interior of the country, and of which little was as yet known.

The winter was occupied in and about Lyell examining the local geology, superintending the operations of our prospecting party, and collecting men and materials for our expedition.

We found that Lyell stands on a coal-field, and we had, therefore, little difficulty in obtaining a portable steam boring plant, and after having the furnace modified so as to consume wood fuel, we sent the machine in sections to Red River to be transported overland to the scene of operations. As this would be a difficult and possibly a lengthy operation, we did not propose to go ourselves until some weeks had elapsed, but to leave

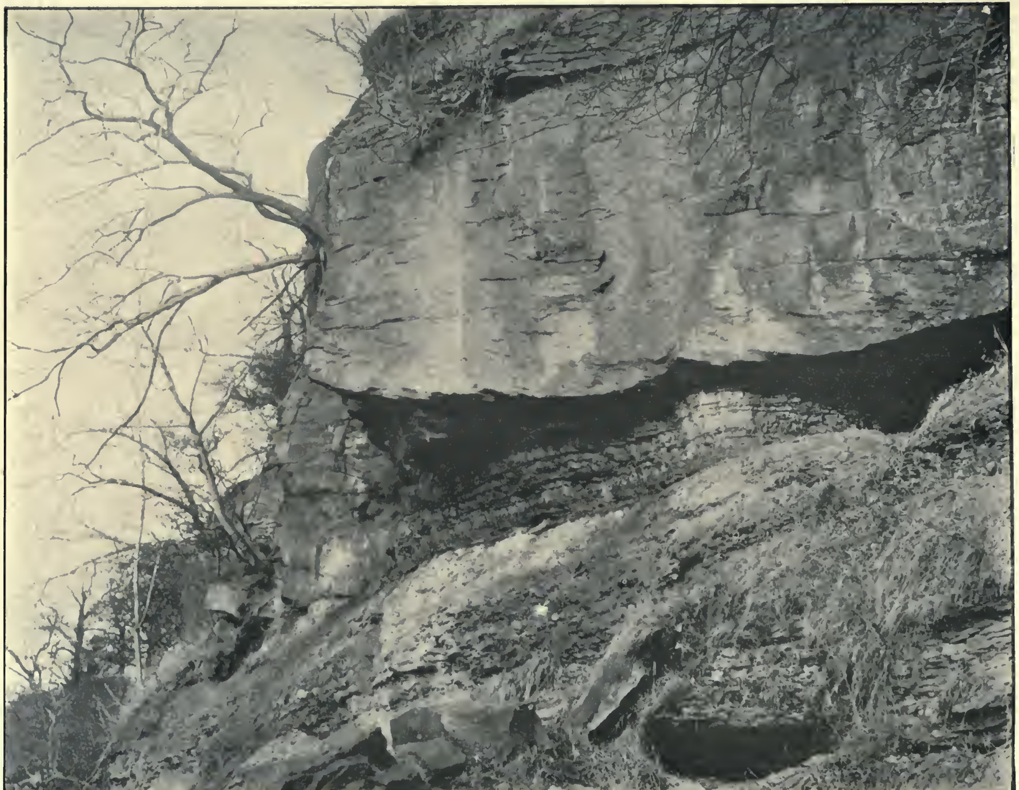

PLATE VI.—Section of Coal-seam on Bank of River.

matters in the hands of our prospector, who was reliable and had had considerable experience in the handling of men.

Before settling down to the regular exploration of the Lyell district there was one point which we wished to clear up, and that was the relationship of the Permian limestones to the rocks below them.

With this object in view, we travelled eastward along the foot of the escarpment, but for some distance, so dense was the vegetation, no exposures of rock could be seen. Eventually in a small rapid stream which flowed down the face of the escarpment we encountered bare rock.

In the lower part of the stream course there was a section of dark-gray shales with very numerous impressions of fern fronds, or the foliage of some fern-like plant, and near the base of the section was a seam of coal about one inch in thickness. These rocks seemed to dip to the south-west at an angle of 20°, but as the section was small and somewhat obscured by a small land-slide, we could not determine either the direction or amount with accuracy.

Some twenty yards farther up the stream was another section in yellow sandstone which had a southerly dip of 11° and was succeeded by the Permian limestones which were strictly conformable with it.

Although the actual junction of the Permian sandstone, for, since it was conformable with the limestone above, we decided it was of that age, with the coal-bearing shales was not visible, we concluded that there was an unconformity, since both the direction and amount of dip of the former were different from those of the latter.

Several small sections occurred at intervals along the escarpment, but none of them was very clear. On the whole, however, they confirmed us in our opinion that there was an unconformity. No really important section was met with until we reached the valley of the South Fork, a powerful stream which had cut a deep gash in the face of the scarp, and showed the relationship of the beds most clearly.

At the foot of the section was a massive sandstone or grit, made up of rounded and angular fragments of quartz, some of which were sufficiently large to deserve the name of pebbles. This, like the shales in the section nearer Lyell, was seen to dip to the south-west at 20°, while, above it, was to be seen the soft fine-grained yellow sandstone of the Permian, here reduced to a thickness of 10 feet, but again succeeded conformably by the limestones.

In this section the discordance between the dip of the two series of rocks was plainly visible, and the fact that here the Permian rocks rested on a coarse grit, while at Lyell they were upon coal-bearing shales, proves the unconformability of the sequence beyond doubt.

At the head of South Fork the Keuper Sandstone was again visible, and here we also encountered the continuation of the Black Point Dyke, which had now changed its direction to north-east and south-west.

CHAPTER VIII

THE COUNTRY ROUND LYELL—THE COAL-FIELD

THE town of Lyell is built on both sides of the river, which is spanned by two fine bridges. The eastern portion is residential and contains the Government buildings, while the western is devoted to manufactures.

The coal which was used in the various factories was obtained from Coal Hill, an isolated eminence to the north-west of the town.

The supplies from this source were, however, almost exhausted, and as it was the only known source of coal in the country the authorities were much exercised as to the fate of the industries when the fast-diminishing reserves should be worked out.

Under these circumstances we made it our first duty to visit Coal Hill and its neighbourhood, in order to ascertain whether the seams could be traced elsewhere, and also if others might not be discovered.

The hill stands upon an almost level plain above which it rises some 400 feet. It consists for the most part of gray shale, but is capped by a brownish-yellow sandstone with rusty-looking specks in it. This is a hard rock, seems to be durable when exposed to the weather, and has been used as a building stone in Lyell, and to some extent also in Port Hutton and the smaller towns. We called this rock the Coal Hill Sandstone, and examined it carefully as it might serve as a useful index bed in our future investigations.

The sandstone rested on a very dark-gray, almost black, calcareous shale in which were numerous fossils, and was upwards of 60 feet in thickness. Its exact thickness could not be ascertained as the top had been worn away by denudation.

The black shale, which was 10 feet in thickness, contained amongst other fossils many specimens of a shell similar to that of an ordinary scallop, which in most instances were crushed flat and lay one upon another in such profusion that they could be flaked off, one after another, almost like sheets of paper. The fossil was *Pterinopecten papyraceus*, from which we judged that we were dealing with the Upper Carboniferous or true Coal Measures.

Beneath the black shale was 30 feet of gray shale with two bands of nodules of clay ironstone; then followed the upper seam of coal. This was 3 feet 6 inches in thickness, and rested on a 20-foot bed of almost white sandstone containing numerous fossil roots and rootlets in its upper portion, and near its base a cast of the trunk of a large tree. Beneath this was 15 feet of gray shale, and then a 5-foot seam of coal, which in turn rested on a bed of fireclay.

The strata in the lower part of the hill were obscured by talus material which had fallen from above, but there appeared to be at least two beds of white sandstone of the variety known as ganister and similar to that immediately below the upper seam of coal. The seams of coal are known locally as the "top seam" and the "bottom seam," and we shall retain these names, as to introduce others might lead to confusion. The whole of the strata dip south-south-west at 10°.

From our measurements and general survey of the hill we were now able to construct the following section (Fig. 19).

The seams were worked from the low side so as to allow of easy haulage, and also so that the water might readily drain away without the necessity of pumping.

Several bore-holes had been put down in the plain

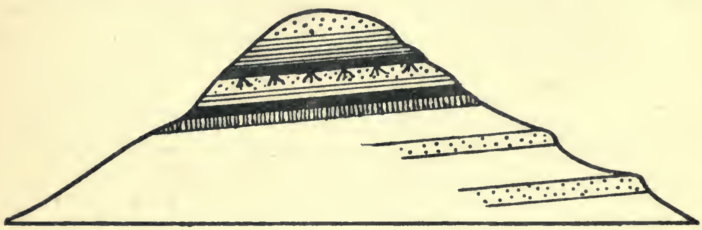

FIG. 19.—Section of Coal Hill.

at the points marked B.H. on the map, but, although in some instances they had reached a depth of over 1000 feet, none of them proved any workable coal. In fact, the deeper they went, the less favourable the conditions appeared.

Doubtless at one time the seams of Coal Hill extended over the whole field, but they have been removed by denudation, so that only the small outlier remains.

We had noticed that the strata were dipping towards the south-south-west, and it was therefore possible that the seams might come down to the level of the plain in that direction.

A careful search from the foot of Coal Hill to that of the Permian escarpment failed to yield any trace of the lost seams, and on making a true-scale section, that is, a section in which the vertical and horizontal scales are the same, we saw that the Bottom Seam would not reach the level of the plain for some distance to the south of the escarpment (Fig. 20).

If the dip of the Coal Measures remained constant at 10°, the Permians dipping at 12°–15°, there was little likelihood of recovering the seams beneath the unconformity, but if the dip of the older series increased towards the south, they might yet be preserved beneath the covering of newer rocks.

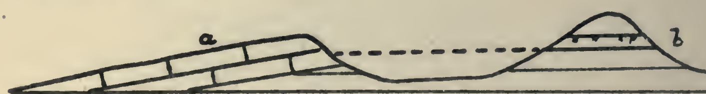

FIG. 20.—*a*, Permian ; *b*, Coal Measures.

Thus we were unable to give a favourable report as to the possibility of finding further reserves in the exposed area of Coal Measures, but we strongly advised exploration by boring to the south of the escarpment. After some demur on the ground of expense, the authorities at Lyell undertook to carry this out under our supervision.

We had now to consider the question of choice of a site for our trial bore, and in this we naturally had to be guided by the probable thickness of Permian and newer rocks, which it would be necessary to penetrate before reaching the underlying Coal Measures.

The Permians dip at 3° in the valley of the West River, and their base is at a level of 650 feet above the sea. From Fig. 21 it will be seen that the depth of a stratum in level country is determined by the distance from the outcrop, measured in the direction of the dip, multiplied by the tangent of the angle of dip. AB is the distance from the outcrop, and BC is the depth of the stratum at B, and $\frac{BC}{AB}$ is the tangent of the angle BAC.

$$\frac{BC}{AB} = \text{tan. BAC.}$$

$$BC = AB \times \text{tan. BAC.}$$

From this it follows that the farther we go to the south the greater will be the depth of the base of the Permian. For this reason we must choose a site as near the outcrop as is consistent with our object of exploring as far to the south as possible.

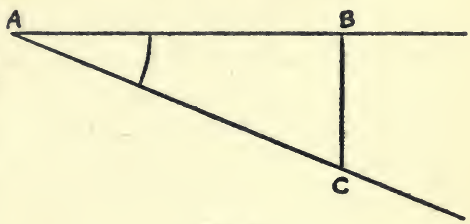

Fig. 21.

On the whole, a point in the valley of the West River would be most suitable, as we could there obtain the water necessary for the work, and after looking over the ground we selected a point marked B.H. No. 2 on the map. This lay exactly 2 miles south of the outcrop of the base of the Permian, and was at an elevation of 750 feet above sea-level.

The base of the Permian will fall in 1 mile, 1 mile = 5280 feet × tan. 3°. From a book of tables we find that tan. 3° = 0·0524. The fall in feet per mile will therefore be 5280 × 0·0524 = 276·6.

Our site was 2 miles from the outcrop, and the fall would therefore be $276 \cdot 6 \times 2$ = roughly, 550 feet.

At the outcrop the base of the Permian was 650 feet above the sea, and at our site $650 - 550 = 100$ feet.

We now had the level of our site 750 feet and the level of the Permian base 100 feet, and it was therefore obvious that its depth below our feet would be 650 feet. The surfaces of beds of rock are by no means plane surfaces, and the surfaces below unconformities are often extremely irregular, and some allowance must be made for this.

Taking all things into consideration, however, we expected to penetrate the Coal Measures at a depth of between 650 and 700 feet.

The rock at the surface was Keuper Sandstone, and this would have to be passed through before the Permian limestones were reached.

As the completion of the bore-hole would take many months, we should not be able to be present during the operation. It was therefore necessary for the boring to be done with a diamond drill such as would bring up cores, and these could then be preserved, carefully numbered, for our subsequent examination.

In the meantime we continued our exploration of the country in the neighbourhood of Lyell.

Some 15 miles above the town the river receives two large tributaries, one on either bank. The one to the west, Shale Creek, was navigable for canoes for about 50 miles, and offered an easy route into the area north of Coal Hill, much of which had been very imperfectly explored. After some little delay we managed to get two large and two smaller canoes, and made a start up-stream with provisions sufficient for one month, leaving instructions that further supplies should be sent after us a fortnight later. There was said to be abundant game in the forests of the region we intended to visit, so we had little fear of starvation even if the supplies failed to reach us.

The valley of the Hutton River above the town was much narrower and possessed steeper banks than in the portion of its course which lay below the Permian escarpment. There was also very little alluvium, the banks being cut in the shales and sandstones of the Coal Measures.

Arrived at the mouth of Shale Creek we landed to inspect the cores from one of the trial holes close by. After some difficulty the spot was located, but we found that the building in which the cores had been stored had become unroofed and that the specimens had for the most part crumbled to powder. This was disappointing, for we had been in hopes that we might have obtained fossils from these cores which might have been a guide to the portion of the series to which they belonged.

After a thorough exploration of this neighbourhood, without seeing a single exposure of solid rock, we returned to the river, and here, as we paddled up Shale Creek, we were more fortunate, as there were good sections in the river banks.

For many miles we traversed ganisters and ordinary brown sandstones, with here and there a bed of shale. We were travelling along the strike of the beds for the most of the way, and therefore there was little variety.

Of fossils there were few, and these were of little interest. Casts of *Calamites*, which ranges right through the Carboniferous Series, and a few *Stigmaria*, the roots of one or more of the larger trees which flourished during the period.

As regards the vegetation of the valley we found that belts of forest alternated with park-lands covered with a luxuriant growth of grass and studded here and there with groups of trees.

Birds of the pheasant type, and occasionally a deer, fell to our guns, and in this way we were able to avoid the undue depletion of our stock of provisions.

The main object of our journey was, of course, the discovery of coal, and in this respect we had been so far unsuccessful. So far as we could tell the rocks through which the creek had cut its channel belonged to the very lowest part of the Coal Measures, and in these there seemed to be no workable seams. In one place there was a bed of very poor quality coal, measuring from 3 to 3½ inches in thickness, but this was, of course, of no value. However, we continued our journey to the limit of navigation in the hopes of encountering something of a more promising nature.

There were surprisingly few tributaries, and as the country was for the most part densely wooded, we had little chance of exploring to the right and left of the stream.

At last, however, we reached the mouth of a considerable stream which flowed in from the west and which therefore promised more variety, as giving a change of direction—it would probably take us off the line of strike. While debating as to whether we should follow the main stream or the tributary we heard a shot fired in the forest not more than half a mile away.

In order to attract attention we fired a gun in reply, and in about half an hour were rewarded by the appearance of a man of apparently sixty years of age. He was an Englishman and told us that he had been living here for some ten years, though he seemed a little doubtful as to the exact number. He was very reserved and would say nothing about his past, but appeared glad to see us, and invited us to his house to share in a deer which he had shot. Leaving our men in charge of the canoes and stores we made our way, in the company of our new friend, along a narrow pathway through the undergrowth for a distance of about a quarter of a mile from the fork of the stream. We soon found ourselves in a small clearing in front of a steep face of sandstone, under the shelter of which stood a somewhat primitive log hut.

Eventually convinced of the *bonâ fides* of our host we offered to lend him two of our men to assist in carrying home the deer, and returned to the canoes to bring up some tinned fruit, and other delicacies, which we hoped might prove a pleasing variety in the diet of the hermit.

On our return we were surprised and highly pleased to find him carrying a basket of excellent coal, which he informed us he had dug out of the river bank a little farther up the main stream. This we supposed to be derived from some thin seam such as those we had encountered from time to time in the lower reaches of the river, but decided to visit the spot on the morrow.

As our host appeared to be very reluctant to tell us his name, or to say why and when he retired to these wilds, we christened him the "Hermit" and decided to respect his incognito.

Next morning, on accompanying him to his mine, we were surprised to find an open exposure of a seam of excellent coal, 10 feet in thickness and dipping to the north-west almost at right angles to the direction of dip of the measures farther down-stream (Plate VI.).

At the fork there were clear exposures of beds dipping south-west, so there must clearly be a disturbance between that point and the outcrop of the seam. It was impossible to follow the section down-stream on foot as the river entered a gorge cut in a

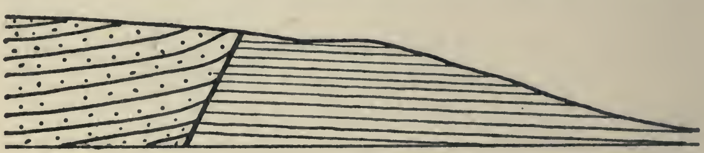

FIG. 22.

hard sandstone, and the water occupied this from side to side.

We therefore returned to the "Hermitage," as we had christened the place, and thence to the canoes. On paddling up-stream we entered the gorge from its lower end and found ourselves between walls of shale whose beds appeared almost horizontal, again a strike section, and then we suddenly came upon a fault which brought in the sandstone with a strong dip to the north-west (Fig. 22).

The dip rapidly diminished as we passed up-stream until, on reaching the Hermit's mine, it had fallen to 12°.

We determined to call the thick seam the "Hermit Mine," and if it covered any considerable area it promised to play an important part in the history of the country.

From fossil evidence it was clear that we were here dealing with a portion of the Coal Measures, altogether higher in the series than any of the beds exposed near Coal Hill, and we therefore determined to follow the stream still higher. Within the next two miles we discovered the outcrops of three other seams, with an aggregate thickness of 15 feet and, so far as we could tell from a field examination, of excellent quality.

Beyond the outcrop of the highest seam the water shallowed rapidly, and our onward progress was arrested as the undergrowth was so dense as to render further advance impossible except by cutting a passage with axes, and as we had not come prepared for this kind of work, we had perforce to retreat. We had, however, discovered what promised to be a very rich coal-field, and could safely leave its further exploration to the officials of the Government.

Before leaving the district we ascended the tributary in order if possible to locate another point on the line of the great fault, so as to be able to plot its direction on our map with a greater degree of accuracy than is possible from an observation in a single locality.

The valley of the tributary was not so deeply cut as that of the main stream, and consequently there were fewer clear sections of the strata. We were able, nevertheless, to locate our line by a sudden change in the elevation of the country, due to the presence of the hard sandstone, and on joining the point where the change in level occurred with the position of the fault on Shale Creek, we found that the line passed along the face of the precipitous rock behind the Hermitage.

The journey back to the main river was accomplished much more rapidly than the outward one, as we were now travelling with the current. On the way we met our second party with the provisions, and decided therefore to explore East River, the tributary on the east side of the Hutton. To reach the mouth of this we had first to travel a short distance up the river from the mouth of Shale Creek.

The dip of the rocks in the lower part of the course of East River was down-stream, and thus we might expect to meet with rocks older than the Coal Measures as we reached its higher waters.

Shales and ganisters similar to those seen in Shale Creek formed the banks of the river during the first part of the journey, which lay across a rolling plain. Then, with a change to hilly country, there appeared a very coarse-grained sandstone or grit, in which some of the grains, which were angular in character, were so large as to warrant the name of pebbles.

Amongst the beds of grit occurred several beds of shale with a few ill-preserved fossil shells. These belonged to the Brachiopoda, and it was therefore evident that the beds were marine deposits, as no fresh-water Brachiopods are known.

In parts of the British Isles a series of coarse grits, alternating with shales, occurs below the Coal Measures, and is there known as the Millstone Grit, and as our sandstones and shales are like in character and position in the series we may adopt the name, though, of course, it is not possible to definitely correlate the two series.

On drawing water from the river for washing purposes, we were surprised to find that it was remarkably hard, so much so in fact that it was almost impossible to obtain a lather, and some pebbles obtained from the river bed were found to be coated with a layer of calcium carbonate, of a spongy texture and arranged in concentric layers, also our kettle soon became coated on the inside with a deposit of scale.

From these circumstances it was obvious that there must be a large amount of calcium carbonate dissolved in the water, and we therefore suspected the existence of a thick limestone somewhere in the upper parts of the river basin.

Pursuing our journey we arrived at a point where the stream divided, and as the branch on the left hand appeared to be the larger we decided to follow this, and eventually found ourselves in front of a great cliff of limestone, at the foot of which was a cave from which the river issued.

Returning now to the point of junction, we determined to ascend the other branch on the chance that by its means we might obtain access to the country to the north-east. Here, again, the stream divided ; one branch, which flowed from the north-east, appeared to issue from the foot of the limestone cliff, was not navigable, and the other was evidently the South Fork, whose upper course we had already examined.

In order to effectively explore this region it would be necessary to establish a camp and provision it for some weeks, as from the roughness of the country it would appear that much of our exploration must be done on foot. Under these circumstances it was advisable to return to Lyell, especially as we were anxious to know how our borings were progressing.

On arrival at Lyell we found that considerable outcry had been raised in the local Parliament against the expenditure of public moneys on our so-called wild-cat schemes of obtaining coal from beneath the red rocks to the south, chiefly by the opponents of the party in power for purely political motives, but also by a section of the Government who were very anxious to promote certain expensive schemes for the utilization of water-power through the medium of electricity, and to which cheap fuel would be fatal.

We were particularly anxious, for purely scientific reasons, that the bore-holes should be carried on, and were somewhat doubtful how our announcement of the discovery of the Hermitage Coal-Field would affect the question.

The Premier expressed himself highly pleased with this discovery, and assured us that, contrary to our expectations, it would remove all shadow of opposition to the financing of our boring operations.

It appears that on our arrival we were looked upon as people who had had a scientific university training, and were consequently, in the sight of "practical men," mere visionaries who might know something of fossil shells and such-like "curiosities," but who, when it came to the test of utility, were generally found wanting. Yet our chance discovery of the Hermitage seams, for which the credit was really due to our eccentric friend the Hermit, raised us to the height of popularity and, as we

PLATE VII.—Limestone Wilderness on the top of Cliff.

thought, removed once and for all any opposition to the employment of national funds for the purposes of our expedition.

There was no news awaiting us from our prospector, and therefore we decided to visit the two bore-holes so as to be able to report progress.

For this purpose we once more boarded the steamer and steamed down the Hutton to the nearest point to B.H. 1, where we mounted the horses we had taken with us, and after two days' somewhat difficult travelling came to the scene of operations.

We found that work had been stopped owing to lack of water for the boiler, as there had been no rain for several weeks, and although a small reservoir had been made, the stock had been exhausted. It was, of course, impossible to use the water of the spring, as this was impregnated with salt. The boring had progressed to a depth of 170 feet, and a thin seam of gypsum had been penetrated, but as yet no rock salt had been encountered.

At 110 feet a bed of sandstone had been entered, and this extended down to 130 feet from the surface. This we were able to ascertain from the cores which had been carefully preserved.

The prospector had been away for some days at the other bore-hole, and the man he had left in charge when the reservoir ran dry had stopped work to wait for instructions.

On examining the bore-hole we found that it was full of fresh water up to a point 20 feet from the surface, and on starting up the engine on a small quantity of somewhat dirty water which remained in the bottom of a tank, and attaching the pump, we found that we were able to draw considerable supplies from the bore-hole without materially lowering the level of the water. Here, then, was the solution of our difficulties, and we gave instructions to start a fresh bore-hole and to utilize the old one for water-supply.

In case we should miss the prospector on our way to B.H. 2 we left written instructions for him to line the second bore-hole with iron pipes when he should reach the sandstone, so as to keep out the water and avoid interfering with the supply from the first hole. We thought it wise to spend a few days here and see the new hole well under way before leaving for B.H. 2.

The journey to B.H. 2 was very uninteresting from a geological point of view, as there were no exposures of the solid rock until we arrived within a few miles of the camp. Here we found operations in full swing. The red sandstone had proved to be but thin, and the Permian limestone had been penetrated at a depth of 270 feet. At the time of our visit the bore-hole had reached a depth of 316 feet and was still in the limestone series.

Having given instructions as to the continuance of the work, we returned to the steamer, and later to Lyell, well satisfied, on the whole, with the results of our work.

CHAPTER IX

THE COUNTRY ROUND LYELL—THE NORTH-EAST

OUR camp equipment, consisting of four military bell-tents, and the usual outfit of cooking utensils and tools, was obtained from the steamer and, together with the necessary provisions, was stored in boats and we once more set out for East River, with the object of making a more detailed examination of the "Millstone Grit," and, if possible, penetrating the country beyond the limestone cliff.

Arrived in the grit country we found it easy to make expeditions on foot to right and left of the stream, as the forest had given place to grass and heather-covered hills. Many of these were formed of the massive grits, while the intervening shales were exposed in the valleys between. The dip of these beds, like that of the Coal Measures, was towards the south-west and at a low, though variable, angle.

A close examination of the grits showed them to consist of angular grains of quartz, with occasional pink felspars, and from the coarsest layer we obtained two small pebbles of granite. A careful search failed to reveal any pebbles of limestone in the grit even near to the great line of cliffs. A suggestion that the cliffs represented a former shore-line, and the grits a beach deposit, would therefore appear to be untenable.

The grit seemed to be the débris of some mass of granite or similar rock, as, even where felspar was absent, some of the cavities between the grains contained white powdery Kaolin (china clay), which is known to be a decomposition product of felspar. The third constituent of granite, the mica, was plentiful in the shales associated with the grits.

As we might be making a somewhat lengthy stay in this neighbourhood more care than usual was necessary in selecting a camping-ground, and we finally chose a velvety lawn, which sloped down to the stream near the entrance to the large cave. This spot was picturesque in the extreme; on one side of our tents towered the cliff of limestone, 250 feet in height, while to the left and behind us the ground was thickly covered by birch woods. In front the meadow stretched down to the river, and on the opposite bank the birch trees were within a few feet of the water. Willows and alders overhung the river, while behind the woods curved the majestic cliffs of the amphitheatre, now tinted crimson by the rays of the setting sun.

Thus our temporary home was well protected from the winds, and behind the first row of trees to the left was a long deep pool in the river which formed an ideal natural swimming-bath. A small spring issued near the cliff foot just above the camp and flowed within a few yards of the tents. In fact, the place seemed as though it had been designed for our purpose.

The final arrangement of the camp had to be left until the morrow, but, in the meantime, we proceeded to erect two of the tents, one for ourselves and one for our attendants, and to set about cooking supper.

The work of bringing up the stores from the boats, and of arranging the camp, occupied the greater part of the next day, but in the evening we made an attempt to explore the large cave from which the river issued. On our side of the river the water washed against the wall of the cave, but on the opposite bank there appeared to be a ledge of rock about 2 feet above the water-level. We must, therefore, enter by that side, and as it was some distance to where we had left the boats, it would be necessary to wait for another day.

Next morning, after a swim in the pool and an early breakfast, we crossed to the far bank and made our way along the riverside to the mouth of the cave. Here we found a broad flat ledge of rock between the side of the cave and the water. It was smooth and water-worn, showing that, in wet weather, the water rose considerably above its present level, and warned us not to enter the cave after heavy rains in the hilly country behind, as we knew that these underground rivers often rise very suddenly. Should this happen while we were at any distance from the entrance, our retreat might be cut off.

Walking along the ledge, at times able to stand upright, at others having to stoop and occasionally to creep on all fours, we found that we were able to penetrate for a distance which we estimated at 300 yards, but at this point our onward progress was stopped by the ledge narrowing, and eventually coming to an end, so that the river filled the cave from side to side.

One of our number attempted to swim up the channel and succeeded in penetrating some distance farther, but as there was no sign of a landing on either side, and the water was extremely cold, he was compelled to return.

The water in the cave was still and deep, being held up by a natural weir made up of an accumulation of boulders just outside the entrance. It was clear that for any further exploration we should require a light canoe, and as there was every sign of the cave penetrating far into the mountain, we decided to send two of our men down to Lyell to procure one, and also a supply of ropes and, if possible, rope-ladders, as these might be required if much underground exploration was to be carried out. A large supply of tallow candles, some magnesium powder for underground photography, and two iron drums containing a powerful colouring matter called fluorescein, which we had brought out with us from home, might also be required.

Having returned to the light of day and partaken of our midday meal, we next turned our attention to determining the relationship between the massive limestone of the cliff and the "Millstone Grit" lower down-stream.

Following the course of the river, we found several exposures of the limestone with a dip of from 2° to 5° to the north-east. From this it would at first sight appear that the limestone was newer than and resting upon the grit, but when we remembered that only some few miles down-stream the grit was dipping in the opposite direction, and passed conformably below the Coal Measures, there was clearly no room for the massive limestone, which must be at least 500 feet in thickness, in the series. On following the stream still farther in a downward direction, we found several reefs of grit dipping at a high angle towards the south-west exposed in its bed, and thus must have passed the line of junction.

We now set ourselves to work to narrow down the space between these reefs and the lowest exposure of the limestone, and were so far successful as to find a small exposure of grit in the bank about 30 yards up-stream from the uppermost reef. On the other hand, a careful search revealed the presence of limestone within 50 yards of this, but this was the nearest approach to the junction which we were able to make.

Somewhere in this space of 50 yards lay the contact of the two rocks, but as it was obscured by loose material we could only determine its nature by inference.

In a small, very much weathered, exposure of the limestone, which we stopped to examine on our way back to camp, we found a large mass of fossil coral almost entirely weathered out from the surrounding mass of limestone. This was recognized as *Syringopora ramulosa*, which is characteristic of the Lower Carboniferous. From this determination it was clear that the limestone was older than the grit, and this, together with the change of dip, led us to infer that the junction between the two rocks was a faulted one (Fig. 23).

This dislocation we called provisionally the "Camp Fault."

Next morning we were up before sunrise fitting out the boat which was to go down to Lyell for the canoe and ropes and as much in the way of provisions as it was possible to carry in addition.

This being accomplished and the party dispatched, we set out to explore the country beyond the cliff. It was first necessary to find a point where the cliff could be scaled. Climbing on these limestone rocks is often dangerous, owing to their being loose and rotten near the surface, and the holds, in consequence, extremely treacherous.

Crossing the river and walking towards the north-west, we found that the cliffs were not so high and that large quantities of fallen material had accumulated as a "talus" along their foot. Still farther on, the rough talus was replaced by a grassy slope, surmounted by the

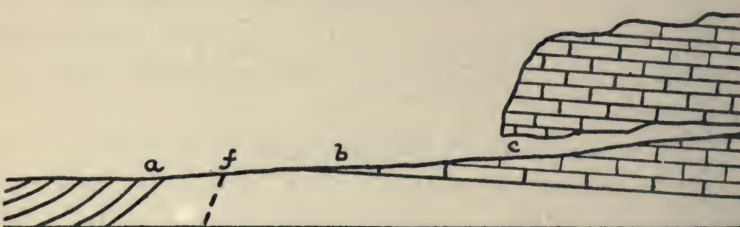

FIG. 23.—*a*, Reefs of Grit in bed of stream ; *b*, Limestone ; *c*, Cave ; *f*, Supposed position of fault.

continuation of the cliff-line, now only some 50 feet in height. Numerous gulleys occurred in this part of the cliff, and one of them gave easy access to the summit.

On reaching the top of the cliff we found ourselves on the edge of a wilderness of bare limestone, which extended as far as the eye could reach, rising terrace upon terrace, and uninterrupted except by an occasional stunted tree, rooted in some crevice, and distorted by the keen winds which prevailed on this upland plateau (Plate VII.).

The surface consisted of great slabs of limestone, intersected by numerous deep rifts, on the bottom and sides of which grew mosses, lichens, and ferns (Plate VIII.). To walk over the surface of these clints, as such limestone wastes are called in the North of England, was a very toilsome proceeding, and we therefore walked along the edge of the cliff seeking some easier means of access to the distant hills which we could see beyond the plateau.

Arrived at a point immediately above our camp we found that the valley at the foot of the cliff was continued by another one running in the same direction at its summit, and that the great slab of rock on which we stood appeared to have been at one time the sill or crest of a great waterfall. There was now no sign of flowing water in the upper valley and no indication that water had recently flowed through it. The rock of the sill was partly overgrown by lichens, and ferns and mosses occupied the crevices between its various slabs. Wending our way up this dry valley, we found that its floor was in places flat and covered with short rich grass, but more usually encumbered with boulders of angular form which had fallen from its walls. Travelling was fairly easy in this valley, but even here we encountered at intervals clint-like surfaces with numerous open joints which would render movement after nightfall extremely dangerous.

As we were now a considerable distance from camp we found that it would be impossible to continue our exploration without making arrangements to spend nights as well as days upon the plateau. This being the case, we returned to camp, and on the following day again climbed to the higher ground, this time accompanied by men carrying sleeping bags, provisions, and a small tent.

Of the five men we brought with us, two had gone down to Lyell, two were with us, and the remaining one was left in charge of the stores at the main camp.

Penetrating the dry valley beyond the point where we were compelled to turn back on the previous day, we eventually came to the foot of a second cliff, in this instance only 60 feet in height, which bore signs of having been, like the larger one below, the site of a waterfall (Plate IX.).

Ascending with little difficulty, we again traversed a dry valley with a third cliff and dried-up waterfall at its head. Here, however, were signs that water had recently flowed, there being accumulations of mud and dry twisted grass and sticks amongst the stones which formed a crater-like hollow at the foot of the cliff.

Above this third fall the valley was again continued towards the north-east, but there was no lichen on the rocks of the valley floor, and signs of the recent action of running water were everywhere evident.

We decided to spend the night in a sheltered nook near the foot of this third cliff. A small recess in the limestone formed a natural fire-place, and sufficient fuel to last the night was to be found amongst the debris at the foot of the fall.

Towards sun-down heavy clouds began to collect on the hills and a few rolls of distant thunder warned us that we might get a wetting before the morning, as the light tent we had with us, though it was sufficient to protect us from the dew or even a shower, was useless to turn a heavy downpour.

Under these circumstances we made a hasty exploration of our immediate neighbourhood to endeavour to find some natural shelter, but without success, until one of the party came upon an opening less than 2 feet in height near the foot of the cliff. This did not appear promising, but he said it would serve him for a bed-chamber in case of emergency as it extended some 10 feet into the rock and then terminated abruptly. There would be just room for one man to lie, and though it might turn out to be rather stuffy it would at all events be dry.

Leaving the "Troglodyte," as we at once christened him, to prepare his chamber, we were just returning from a fruitless search on the opposite side of the valley, having made up our minds to face the worst, when we heard him calling and saw him standing outside his cave beckoning to us excitedly.

On reaching him he told us that he had found a small opening or chimney in the roof of his bed-chamber and that with assistance he thought that he would be able to climb it. It was on striking a match to light his pipe that he had noticed the opening.

With some assistance the Troglodyte managed to scramble up the chimney, and called down to us that he was in a large dry chamber, but could not say how large. With one man at the top to assist, it was an easy matter for the rest to join him, and there, sure enough, was a large cavern, so far as we could judge about 30 feet high and of about the same width, leading off in both directions from the hole up which we had climbed and running parallel to the face of the cliff outside.

To our left—that is towards the dry valley—the floor of the cave fell away rather steeply, but to the right it was level for some 20 yards, and then rose rapidly, at the same time narrowing rather abruptly. There was found to be a gentle current of air from below which passed on into this upper and narrower part of the cave.

On obtaining an armful of dry grass from outside and setting fire to it, we found that the smoke was carried away up the passage, and that in consequence we could light a fire without fear of suffocation.

Here, then, was an ideal shelter for the night, and we at once set to work to collect our belongings from the valley and to transport them to our new home, in the meantime setting the men to collect and bring up all the fuel they could find.

Scarcely were our preparations complete, when the storm burst upon us, and we were glad to retreat to our cavern. Lighting a fire, we were able to cook supper and arrange our sleeping bags for the night, and as we owed its discovery to him, the Troglodyte was put in charge. Before turning in for the night one of the party climbed down to the entrance and reported that the storm was over, only distant rumblings of thunder and occasional flashes of sheet-lightning now remaining.

Even at the very height of the storm the thunder could only be heard in the cave with difficulty, owing, we supposed, to the narrowness of the entrance. We were therefore much surprised to be awakened just after midnight by a loud rumbling which rapidly increased to a continuous roar, while the air in the cavern appeared to vibrate so that we could not tell whence the noises came.

PLATE VIII.—Limestone Clints.

The fire was still burning, and by the light of some pieces of resinous pine-wood, which we had reserved for this purpose from our stock of fuel, we set out to explore the lower end of the cave. At a distance of some 80 yards from the entrance, some 70 feet below the level of our sleeping floor, and at a point which we judged to be very near the dry waterfall, we came upon the mouth of a well or shaft from which the roaring was found to proceed, and here the echoes of the cavern being eliminated, we were able to recognize the noise as that of falling water. By holding one of our torches head downwards we were able to get it into a vigorous blaze, and then, throwing it into the abyss, to obtain a momentary glimpse of a great mass of falling water at a depth which was variously estimated at from 100 to 150 feet below.

On carefully examining the lip of the abyss we found no trace of the waters having reached this level at a recent time, and thus reassured, we returned to our bed-chamber, and having replenished the fire, once more crept into our sleeping bags, and in spite of the roar of the fall slept soundly.

On waking we were annoyed to find that it was already 10 a.m. and that outside the sun was shining brightly, though no glimmer of light reached our subterranean dwelling.

We noticed before leaving the cave that a small stream of water was flowing along its floor from the direction of the opening which had taken the smoke from our fire, and that this had filled several deep hollows in the floor of the lower part of the cave. We were careful to prevent the pollution of this, for water is very difficult to obtain on these limestone wastes, except during actual rain, as almost all the drainage is underground.

On visiting the dry waterfall of the night before we found that a large stream was pouring over it and falling into the crater below, which was half filled, but was evidently not so full as it had been during the night. No water was flowing down the valley below the crater, and from this we judged that the outlet must be subterranean, and that it was this water which in its further course had disturbed us during the night.

We determined to fully explore the lower part of the cave as soon as the stream should be once more dry and our apparatus have arrived from Lyell.

In the meantime we continued our exploration of the plateau. Making our way round the cliffs to the head of the waterfall, we found a roaring torrent descending a steep and somewhat narrow valley, and on climbing to the summit of a low eminence, we saw before us a level grass-covered plain with a small lake or tarn in its centre, and behind this, and rising about 1000 feet above it, terraced mountains with flat tops.

Flowing towards us from the foot of the lake was a broad river shining in the sunlight; at a point about midway between our standpoint and the lake, the river appeared to suddenly diminish to less than half its volume and then to flow on to the head of the waterfall which we had just left.

Close to the point where the stream diminished, the character of the scenery changed, and the grassy plane gave place to the limestone clints on which we stood.

From this it appeared that there was some change in the nature of the rock, and we therefore returned to the stream with the object of following it across the boundary to seek exposures of rock which might serve to settle the matter.

On the way up the valley it was found that the limestone was still dipping at about 5° towards the north-east, as it had done consistently over the whole surface of the plateau yet explored, and under these circumstances we expected to meet with newer rocks beyond the boundary, possibly with the "Millstone Grit."

On arrival at the end of the clints we found that the stream really did diminish in volume by an extraordinary extent, and as we could see the water running down the open fissures in the limestone on both banks, it was obvious that the greater part of the stream was passing underground.

A little farther up stream we found exposures of a dull-gray shale the bedding of which was much confused, but so far as we could judge there was a dip of 70° to the south. This observation was confirmed by an examination of another exposure in which the beds were better marked, there being a thin bed of limestone which clearly dipped 73° south included in the shales.

Near the foot of the lake the stream had cut a short gorge about 20 feet deep, and here the series was seen to be bent into an anticlinal fold, the limbs of which were almost parallel. Here the limestone bed was well exposed but now dipped towards the *north* at 80°.

In the limestone bed were fragments of trilobites, one of which appeared to belong to the genus *Staurocephalus*, while another was certainly a *Calymene*, and from this we judged that we were dealing with rocks of Silurian age.

The dips of the Carboniferous Limestone and of these Silurian beds were so discordant as to preclude the idea of a conformable junction, and as a whole formation, the Devonian, which should lie between the Silurian and Carboniferous, appeared to be absent, it was clear we must be dealing with either a fault or a great unconformity. The direction of dip of the Carboniferous favoured the former, but it would be well to seek direct evidence before coming to a definite conclusion on the point.

With this object in view we followed the boundary line, and presently reached a low, brown, heath-covered hill, surrounded on all sides by limestone clints. Investigation proved this to consist of "Millstone Grit," and the junction with the underlying Carboniferous Limestone was clearly conformable.

The grit could be traced to within 50 yards of an exposure of the gray shales, the intervening country being occupied by Carboniferous Limestone.

It now became clear that there was no room in the section for the Carboniferous Limestone which we knew to be at least 600 feet in thickness in this district, so that we were again driven to the conclusion that the junction was a faulted one, and that the throw of the fault was at least 600 feet.

A north-east to south-west section through the hill would thus be shown in Fig. 24. This fault, which appeared to run parallel to the Camp Fault, we called the Lake Fault.

From the top of the brown hill we could see away to the north another stream which flowed across the line of the fault, and then disappeared in a dark chasm of the clint area.

As the weather appeared once more settled we could safely sleep out in the open, and therefore pushed on up the lake-side with our sleeping bags and tent, and camped for the night in a clump of fir trees at the head of the lake, and at the mouth of a stream flowing down a steep valley from the mountains.

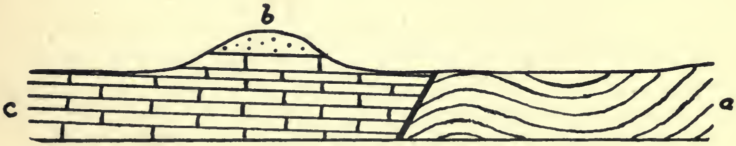

FIG. 24.—*a*, Silurian ; *b*, Millstone Grit ; *c*, Carboniferous Limestone.

The next day's work revealed the fact that the mountains consisted of Carboniferous rocks which rested with a marked unconformity upon shales of Silurian age. The various beds were well exposed, and as the strata were almost horizontal, there was no difficulty in ascertaining their approximate thickness by means of the barometer. First there was a steep slope composed of almost vertical Silurian shales, which was followed by horizontal beds of Carboniferous Limestone, with a thin conglomerate made up of fragments of the Silurian in a limestone matrix, at their base.

These measured 800 feet in thickness, and near their upper surface were a few beds of shale, succeeded by 300 feet of coarse "Millstone Grit," which formed the flat tops of the hills.

The talus heaps that occurred at the foot of each of the terraces of which the hillsides were made up, con-contained many fossils, including the large brachiopod *Productus giganteus* and many very beautiful masses of coral, while from the shales below the unconformity we were able to obtain a few somewhat obscure graptolites of the simple types found in the Silurian, thus confirming our previous views as to the age of the shales.

CHAPTER X

THE COUNTRY ROUND LYELL—THE UNDERGROUND DRAINAGE

HAVING returned to our main camp, we spent a few days in the exploration of the country to the south-east, along the foot of the limestone cliff.

At a short distance behind the camp we came upon a deserted stream channel, which, however, showed traces of having carried a considerable flood of water quite recently, probably during the thunderstorm which we experienced on the plateau. On following this channel upwards we found that it ended abruptly in a mass of loose stones, which evidently covered the mouth of some tunnel or cavern from which the waters had issued. This channel we called Blind Burn.

Travelling along the foot of the line of cliffs, or escarpment as we should prefer to call it, we next encountered the East Fork, which flowed over the edge of the plateau in a picturesque fall, and was at once augmented by the waters of several large springs which rose amongst the stones on both sides of the stream, and close to the foot of the escarpment.

The waterfall had produced a great mass of calcareous tufa, and this formed a sort of apron or screen over which the water poured in a thin sheet. The pebbles and some of the rocks in the bed of the stream were also coated with similar material. This tufa consisted of Calcium carbonate ($CaCO_3$), and was evidently deposited from solution in the water of the river, which had dissolved portions of the limestone in and over which it had flowed.

The solution of limestone is possible owing to the presence in the atmosphere, and in consequence in rain water, of Carbonic acid (CO_2). Carbonic acid in the presence of water unites with Calcium carbonate to form a body which is soluble in water, but is very unstable, thus: $CaCO_3 + CO_2 + H_2O = H_2Ca(CO_3)_2$.

There is an equilibrium between these various substances in the solution, and anything which tends to disturb this equilibrium, for example changes of temperature or of pressure, will tend to cause a further solution of calcium carbonate, if such be available, or a deposition of the same substance, should the change be in the opposite direction. Thus when a solution of calcium carbonate, containing as much of the solid as it is capable of holding, is spread out in a thin sheet, or broken into spray as in a waterfall, or falls drop by drop from the roof of a cave, some of its carbonic acid escapes. A corresponding amount of calcium carbonate is deposited in the solid form, as a crust on the rock surface over which the water is spread out, as an apron of tufa on the face of the waterfall, or as stalactites on the roof of the cave.

All the stream and spring waters of this limestone area were saturated with calcium carbonate, and consequently deposits of calcareous tufa were extremely common. One of the most interesting was a deposit which coated the leaves and stems of moss and other plants, forming a spongy and somewhat friable mass, in the neighbourhood of certain limestone springs.

On returning to camp we found that the party had come back from Lyell with the apparatus and provisions, and we therefore determined to set about a thorough investigation of the caves and underground water system with as little delay as possible.

Two of our men appeared to have a rooted objection to underground work, so we decided to leave them in the main camp, charged with the less exacting, but also less interesting, duty of watching over the stores and making rope ladders which we should probably require at a later stage of our exploration. We then provided ourselves with the most portable provisions in our stock, a good supply of candles and some soft clay, the use of which will be explained shortly.

On reaching the far bank of the stream it was necessary to carry the canoe and provisions, as the stream was too rapid and too much encumbered by stones to allow of navigation. Having arrived in an alcove free from wind on the side of the dry ledge, we decided as a necessary precaution to render some of our matches waterproof, in case we should be so unfortunate as to be upset during our subterranean voyage—a by no means unlikely eventuality.

For this purpose we had brought with us a few wax candles, and one of these having been lighted and allowed to burn sufficiently long to form a pool of melted wax around the wick, the heads of a number of ordinary wax vestas were dipped one by one in the melted wax, so as to be thinly coated. As soon as these were hardened they were placed in small metal boxes, one of which was handed to each member of the party, who also carried a supply of ordinary tallow candles in a tin box. Matches thus treated are quite waterproof, and may be easily struck on coarse sand-paper or on a rough rock surface even after a prolonged immersion in water.

Having arrived at the end of the ledge we lighted a torch, embarked in our canoe and paddled up the stream. As our eyes became accustomed to the gloom we found that we were traversing a stream which filled the cave from side to side. The roof was flat and some 20 feet above the level of the water. It was covered by lines of stalactites which were semi-transparent and about 3 to 4 inches in length, being of the thickness of a piece of wheat straw. One set of these lines ran parallel to the length of the cave, while the other set traversed the roof nearly at right angles to the first.

On more careful examination these lines were found to be those of cracks or joints in the limestone roof through which water was slowly oozing. Farther on the roof became much lower, and we had to sit in the canoe in a stooping position to prevent our heads coming into contact with the roof. This was a good opportunity for studying at close quarters the small stalactites, which are produced as follows. A drop of water forms on the line of one of the cracks and gradually increases in size. During this process, owing to the evaporation of some of the water, or perhaps to the escape of some of the carbonic acid, a thin film of carbonate of lime is found covering the surface of the drop. Eventually the drop falls, carrying with it the greater part of the film, but a small part remains attached to the roof in the position formerly occupied by the edges of the drop, and thus forms a ring or short wide tube, on the end of which the next drop collects. This when it falls leaves a little more carbonate of lime on the ring previously formed, and thus the thin tubular stalactites are slowly formed.

The roof became lower and lower as we progressed, and eventually we had to lie on the bottom of the canoe and propel ourselves by pushing with our hands against the roof. We almost despaired of being able to proceed farther when we suddenly glided out from the tunnel into a lofty chamber, of which we could see neither the roof nor the sides. Before venturing to leave the entrance to the tunnel, in case we might not be able to find it again, we took a lump of the soft clay and put a candle in it. When this was lighted we stuck it against the wall of the chamber immediately above the low mouth of the tunnel.

We then paddled straight ahead, the candle we had left behind serving to give us our direction. After about 600 yards—so far as we could estimate it—we came to the shore of the lake, and were able to effect a landing on a platform of limestone strewn with rounded and angular boulders and sand. As this seemed to continue for some distance we determined to explore it farther, but first took the precaution of lifting our canoe out of the water, as it would be extremely unpleasant for us were it to drift away.

Before leaving the canoe we carefully took the compass-bearing of our candle lighthouse, as it would in all probability have burned out before our return, in which case we might have considerable trouble in locating the entrance to the tunnel, and, so far as we knew, it was our only way back to the light of day.

In order to explore the platform we first followed the shore-line to the right, and, at a distance of about 100 yards, reached a point where the water washed against the wall of the chamber. Next we followed this wall away from the lake and found that it was nearly vertical up to a height of about 20 feet, when it curved inwards towards the centre of the chamber, the roof of which we were still unable to see, as the light of our candles and torches failed to penetrate the moisture-laden atmosphere.

Some 70 yards from the water's edge we found an accumulation of stones piled against the wall and forming a rough cone. Shortly after this we came across a canal-like piece of water which emerged from a tunnel and flowed into the lake. Following this we soon found ourselves back at the place where we had left the canoe, having failed to find any way of penetrating farther into the cavern, unless it were by way of the canal at the upper end of the lake. The atmosphere was damp and clammy, and though while moving about we felt uncomfortably hot, we soon began to shiver when standing still, and decided that lunch with some hot soup would be desirable. While this was being prepared by means of our spirit stove we lit up some magnesium wire in a small lamp provided with a reflector, and by its means were able to see the rough dome-like roof some 80 feet above us, and to discover that the wall of rock on the far side of the lake was without opening of any kind with the exception of the one by which we had entered and above which the candle was still burning. Clearly

PLATE IX.—Cliff on Site of Waterfall.

our only hope of penetrating beyond this chamber lay in following the canal, and this we proceeded to do immediately after finishing our lunch.

Having once more launched the canoe, we passed along the shore and followed the canal to the mouth of the tunnel. This we found to be narrow but lofty, and, unlike those of the one by which we entered, the sides sloped together near the top, eventually meeting about 20 feet above the water.

Several times the tunnel turned suddenly at right angles and widened somewhat, but at about a quarter of a mile from the mouth we came upon a barrier of tufa which stretched completely across the stream, and over which the water poured in a thin sheet. The barrier was 10 feet in height, and it was with considerable difficulty that two of us effected a landing upon it, and were able to traverse it from end to end. Above this weir-like barrier the canal continued as far as our lights were able to penetrate, and as the water was deep on the upper side and again filled the tunnel from side to side, we went back to consult with the others as to what should next be done. We did not care to take the risk of swamping or damaging our canoe by trying to haul it over the barrier, and so decided to abandon the exploration for the day, but to return on the morrow to see if some other passage could not be found.

The wall or barrier of tufa was such as we knew to be formed in similar situations in the following manner. The stream originally flowing over its rocky bed reached a low waterfall probably not more than a foot or so in height. As the water poured over the lip of the fall the disturbance caused the escape of some of the carbonic acid and a layer of tufa was deposited on the lip. This layer then gradually increased in height, slowly raising the lip, layer by layer, and impounding the waters behind it, until it eventually reached its present height (Fig 25).

We found the entrance to the lower tunnel without difficulty and soon returned to the outer air, where we were surprised to find that it was already dark. We had been so interested in our work that we had failed to notice the flight of time, but nevertheless felt considerably fatigued by our exertions in the confined and damp atmosphere of the caverns.

Over our evening meal we discussed the chances of

FIG. 25.—Formation and growth of barrier.

a further exploration of the cavern, and came to the conclusion that if this were possible it must be by some outlet from the chamber not yet known to us, and decided that a careful examination of the walls for some other opening must be our next endeavour.

Accordingly, on our next visit, we skirted the shores of the underground lake and examined the walls of the chamber foot by foot, but without success; finally we landed once more on the platform and made a search along its rear wall. We had almost given up hope when one of us climbed up the cone of stones previously noted, and found that a strong draught of air, which nearly extinguished his candle, proceeded from a crevice between the uppermost stones. He called to us and we having joined him at the top of the cone, helped in the removal of some of the stones, which we rolled down on to the platform beneath. The noise caused by the falling stones was almost deafening owing to reverberations from the roof of the chamber.

Eventually our labours were rewarded by the uncovering of a low opening not more than 2 feet high in its highest part, and having provided ourselves with clay, waterproof matches, and a good supply of candles, two of us proceeded to crawl into this. There was no room to go on hands and knees, and we had perforce to lie at full-length, propelling ourselves by pulling with our hands or pushing with our feet against any projection of floor, roof, or walls which presented itself.

After about five minutes of this somewhat arduous mode of progression we lay still to rest and consult as to what should next be done. Eventually we continued our journey and were rewarded by the discovery of a small chamber containing some very beautiful stalactites of a pale pink colour and all curved at their lower ends towards the direction from which we had come. Here, to our great relief, we were able to sit upright, though the roof was still too low to allow of our standing.

The stalactites in this case were very different both in size and structure from those which we had seen in the outer tunnel. They were thick and solid throughout, being formed by a slow oozing of water from a crack in the roof, over their *outer* surfaces. Their strong curvature was a puzzle to us, and it was not until we noticed that it was in the same direction as the current of air, that we were able to offer an explanation of the phenomenon. Close observation showed that the drops of water forming on the ends of the stalactites were blown slightly to one side by the air current, and thus the curvature was produced.

There did not appear to be any way out of the chamber except the one by which we had entered, but the strong draught led us to search for a further orifice. This we were successful in finding by means of the candle flames, and, after breaking away a screen of stalactites, were able to enter a passage even lower than the first. Luckily, after the first few yards the roof rose rapidly, and we were soon able to walk upright, though we were in constant danger of knocking our heads against small stalactites, or other projections from the roof. We could now hear the sound of running water, though it was impossible to say whence it came.

It is extremely difficult to estimate distances underground, and we were unable to determine how far we were from the main chamber or in what direction we had been travelling, when we suddenly came upon a wide opening—the end of our passage. The opening appeared to be high up on the wall of a subterranean chamber, as below us was a vertical cliff, while above we could dimly discern what appeared to be an irregular roof. Throwing lighted matches into the gulf, we variously estimated its death at 50 to 80 feet, and a small pebble flung outwards striking rock and not water assured us that there was a safe landing below. We found it impossible to climb down the slippery face without the aid of a rope, and therefore returned to our friends in the main chamber, who were becoming anxious for our safety, as we had been away from them for nearly four hours.

It was now clearly too late to continue the exploration that day, and as so much time was wasted in travelling between the main chamber and the camp every night and morning, we decided to bring our sleeping bags on our next visit, and further, to establish a food depot at the summit of the cone near the mouth of the small passage. This occupied us the whole of the next day, and the following one was taken up by transporting a length of rope ladder through the low passage, which we named the Creep, a process requiring much exertion and no small amount of manœuvring. Eventually the ladder was hauled through and secured in position at the upper end of the Creep, but by this time we were far too fatigued to undertake the descent, so we returned to the main chamber, partook of supper and retired to our sleeping bags.

When all lights were extinguished and we were lying in absolute darkness, so heavy and oppressive was the silence that even the smallest sound, such as the falling of drops of water from the roof into the lake, appeared startlingly loud, and we were finally lulled off to sleep by a very faint murmur of running or falling water, rendered wonderfully musical and soothing by distance.

After sleeping about eight hours one of the party awoke, and roused the others to partake of breakfast with hot coffee, which was very comforting, as we were somewhat chilled and exceedingly stiff from the exercise of muscles not frequently brought into play, but used to their utmost capacity in our several journeys through the Creep.

After running several times round the platform to wear off some of the stiffness and to get our blood into circulation, we once more started on our voyage of discovery. Arrived at the top of the cliff, we first examined our ladder to see that all was secure, and then commenced the descent. At a depth of 80 feet below the entrance to the Creep, we reached the floor of the second chamber, and found a stream of water flowing through its centre, This stream appeared to be of about the same volume as the one which entered the lake in the main chamber by way of the canal. Suspecting that the Creep had led us into a higher part of the main system of caves, but unable to make more than a rough estimate of distance owing to the winding nature of the passages, we sent two back to the main chamber with instructions to take the canoe up the canal as far as the barrier and there to show a light, in case we might be able to see it from the mouth of the tunnel into which the stream flowed. In the meantime we continued our exploration and found that the stream issued from a low tunnel on the north side of the chamber. This tunnel we were able to follow as the water did not cover the whole width of the floor, and where it did extend to the foot of the wall was shallow enough to permit of our wading.

Shortly the tunnel widened considerably and at the same time became much lower, so that much stooping was necessary. The cross section of this portion of the cave was as in Fig. 26, and the stream meandered from side to side on the broad floor.

Here the stream had found its way along one of the bedding planes of the limestone, which it had slowly widened by solution, forming a broad low cave. On examining the bed of the stream, however, we saw signs of pot-holing action similar to that which we had already observed in surface streams, and also there were many rounded pebbles beneath the water. It would therefore appear that though the original opening had been caused by solution of the limestone along a bedding plane, the actual stream channel was, in part at least, the result of mechanical erosion.

Pursuing our journey through the cave, we had occasionally to crawl along the flat rocks at the side of the stream, and were sometimes compelled to take to the water when the roof became too low to give us

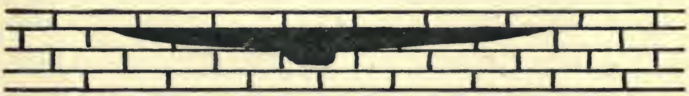

FIG. 26.—Transverse section of a bedding-cave.

passage room on the bank. Eventually the water rose to within a few inches of the top of the passage, and here of course we were brought to a dead stop, and had to return to the second chamber.

On entering the chamber we saw in front of us the opening of the lower or canal tunnel, and at its farther end observed a faint reddish light, which rapidly increased in strength until eventually we saw that it was the light from the torch carried by the men in our canoe below the barrier. They appeared to be about 100 yards down the tunnel, and on our attracting their attention by means of a whistle, one of them climbed on to the weir with the torch, the flame of which was then clearly visible.

We tried to communicate with them by calling, but the echoes so confused the sound that this was impossible. Two of our men had, however, served in the navy, and luckily one of these happened to be with us, and the other in the canoe, and they were able to communicate by means of Morse Code signals, made by alternately exposing and obscuring with the hand, the flame of a candle. By this means we instructed the other party to return to the main chamber and then to meet us in the Creep, to assist in the arduous task of dragging back the rope ladder and other appliances.

Before leaving the upper chamber a thorough examination of its walls was made in order to ascertain if there were any exit other than the three already observed. In this search we were unsuccessful, and had, therefore, to give up any hope of penetrating farther by this route.

On our return journey we made a rough survey of the passages by means of a prismatic compass, using a piece of string 50 feet in length for measuring purposes.

Having collected our stores on the shore of the lake, so that they could be readily brought out by the canoe on its next journey, we embarked once more and drifted down the stream, completing the survey as we went. We arrived at the mouth of the cave at about two o'clock in the afternoon, after having spent three days and nights underground. We were thoroughly tired out with our exertions, and on reaching camp, after a plunge in the pool and a change of clothes, stretched ourselves on the grass in front of the camp, and basked in the glorious afternoon sunshine.

The next day was spent in drawing up a plan of the cave with its various passages and chambers (Fig. 27), and on tracing this on to our surface map we found that the underground river did not follow the dry valley on the surface, but ran almost due north towards the stream which we had previously observed from Brown Hill.

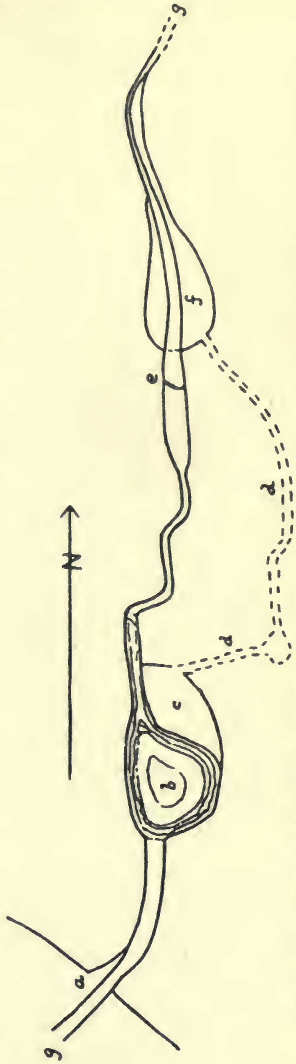

FIG. 27.—Plan of large cave. *a*, Entrance; *b*, Underground Lake; *c*, Platform; *d*, *d*, *d*, The Creep; *e*, The Barrier; *f*, Second Chamber; *g*, *g*, Course of Underground River.

With a view to determining the relation of the surface to the underground drainage, we mixed two pounds of fluorescein powder with an equal weight of potassium carbonate, the object of the latter being to render the fluorescein readily soluble in water. For ease of carriage we made this mixture up in four tins of one pound each, and with these set out for the water sink on the stream which flows from the lake on the Silurian outcrop. We now found that the valley below the sink was quite dry, and that the whole of the surplus waters of the lake passed underground near the point where the stream crossed the fault and flowed on to the limestone.

Here, with the object of ascertaining the ultimate destination of the water, we dissolved our fluorescein in a small dam which we had constructed at the side of the stream by means of stones and turf. When it was thoroughly dissolved we had a deep orange-red liquid, which on being allowed to flow into the main stream and become diluted turned into a glorious vivid green, which glittered in the sunlight and formed, as it rippled and splashed over the stones, a spectacle not readily forgotten. Having watched the green water flow down the sink for some minutes and arranged the dam so that the remaining portion of its contents might dribble slowly into the stream in such a manner as to spread the supply over several hours, we made an inspection of the locality to see if we could find any opening which would admit us to the underground channel. In this search we were unsuccessful, as the water sank amongst loose rounded boulders which completely covered the floor and sides of the crater-like hollow.

As we calculated that several days must elapse before the green water made its appearance at any of the springs in the valley, we decided to make a further collection of fossils from the limestone hills beyond the lake, and therefore made for our old camp beneath the pines.

The fossils were collected bed by bed and a carefully measured section was made as the work proceeded, similar numbers being affixed to the specimens and to the beds of rock in the section. The spoils were carefully packed for transport to the steamer at Lyell, where they could be investigated at leisure. Extensive collections were also made from the Silurian rocks which were found to be well exposed in a gorge on the course of the stream which feeds the lake.

On the return journey it was decided to make a detour to examine the water sink to the north of Brown Hill, and this was found to be quite unlike the one below the lake. We struck the stream about half a mile above the sink and followed its course downwards. It flowed on a floor of limestone between sloping banks of peat, and diminished in volume in a manner now familiar to us, as the sink was approached.

The fall now became steeper, the water rushing over step after step formed by the edges of successive beds of the limestone, but ever diminishing in volume, owing to absorption by the joints in the rocky floor. Eventually we found ourselves in the neck of a great funnel-shaped opening, the sloping sides of which were composed of peat; in front of us yawned a great well-like opening into which the much diminished stream plunged, throwing up clouds of fine, steam-like spray.

By lying face downwards on the limestone slabs, and leaning out over the abyss, we were able to see a ledge of rock on which the water was falling some 70 feet below, only to flow for a few yards and then plunge into a yet deeper chasm which was shrouded in darkness.

This opening, which we decided to call Funnel Sink, though very uninviting in appearance, seemed to offer a possible means of access to the underground channel, and after some discussion we determined to bring up rope ladders and attempt the descent.

In the meantime we returned to the main camp in order to see if the fluorescein had put in an appearance at any of the numerous springs at the foot of the escarpment, which had been carefully watched during our absence by the party left in camp.

Although a regular patrol had been kept up daily, no trace of colour had as yet been seen, and as no further experiments of the kind could be attempted until this lot of colouring matter had been traced and had become exhausted, we decided to rest for a few days, and spent our time in fishing and shooting, meanwhile keeping a sharp look-out on the springs.

At last, on the afternoon of the tenth day after the introduction of the fluorescein at Lake Sink, one of the party who had been fishing in South Fork came into camp and reported that that stream was brilliantly coloured. We at once set out for the stream, and followed it up to the junction of East Burn, down which the green water was found to be flowing. The colour was eventually traced to the large springs which issued at the foot of the escarpment on the north bank of the burn.

Referring to the map, we found that the course taken by the underground water was almost due south, which we remembered was also the direction of the large cave near the camp.

None of the other springs was affected, and as after a further lapse of twenty-four hours the water was once more clear we made ready for our attempt to descend Funnel Sink.

Every available rope with the exception of one long length of thin, but strong mountaineering rope had been made into rope ladders, and had been transported to a comfortable hollow near the sink, and here we repaired with the usual supply of torches, candles, and waterproof matches, and also a supply of fluorescein mixed ready for use.

The following morning the ladders were placed in position, and two of us went down as far as the ledge to prospect, taking the precaution to tie ourselves on to our mountaineering rope, which was slowly paid out by the men above, as each of us made his way down the ladder, thus acting as a life-line in case of a slip.

The ledge we found to consist of slabs of limestone worn smooth and highly polished by the action of the water and offering a somewhat precarious foothold. By the exercise of considerable care we were able to crawl to the edge and to peer over into the lower chasm. A floor consisting of loose boulders was just discernible in the dim light, and by timing the fall of a pebble we estimated it to be over 300 feet below us. Of the walls of the lower chasm we could see nothing beyond some 50 feet below the ledge, and this in spite of the fact that the Sun was shining brightly and there was a fairly good light in the pit.

While we were on the ledge a shower of sand and pebbles came down from the top, narrowly missing one of us, and as it struck the ledge with considerable force we thought it desirable to return to the surface immediately. On the way up the ladders the first man was again saluted with pebbles and sand, but fortunately was not hurt. On reaching the surface we found that with every care it was impossible to avoid dislodging pebbles from the slope when hauling on the life-line, and under these circumstances we began to doubt if it was safe to continue the exploration. In any case the day was now too far advanced to attempt the descent of the lower chasm, so we spent the remaining hours of daylight in examining the rocks in the immediate neighbourhood of the funnel.

Behind a large boulder on the side of the gorge about 20 yards up stream from the edge of the shaft, we found a small opening down which a stream was flowing, and on entering this found that it was possible to penetrate through a narrow cave for some little distance. This cave terminated, so far as we could judge, close behind the main shaft, and we found that near its end the floor fell away rapidly towards an abyss, which we judged communicated with the main shaft at about the level of the ledge, as we could see a faint indication of daylight below, though where we were standing it was quite dark save for the light of our candles. By bringing in an armful of dry heather, setting it alight and throwing it down the pit, we were able to see the bottom, which appeared to be about 400 feet below, and the men we had left outside afterwards told us that the smoke came up the main shaft.

It was, therefore, clear that the two shafts were in communication with each other, and as no ledge was visible in this inner well, and as there was here no danger from falling pebbles, we decided to attempt the descent by this route on the morrow.

There was considerable noise of falling water in the inner shaft, and we had seen faint gleams reflected from what we at first took to be the wet rock walls, when we threw in the blazing heather, and we therefore decided upon a system of signals by means of pistol shots to be used by the men below to inform those above when to pay out, hold on, or haul up the life-line. One shot—stop; two shots—lower away; three—haul up.

On commencing the descent of the ladders it was soon found to be impossible to keep a candle burning as there were strong air currents, and some 50 feet from the surface a small waterfall was encountered. This was spouting out from a cave in the side of the shaft, and at first was a serious obstacle, as the ladder passed clean through it. On continuing the downward journey, however, the ladder was found to pass in behind the main bulk of the water, and only occasional splashes and clouds of spray resembling heavy rain were encountered.

On reaching the level of the ledge, the two shafts were seen to be separated by a curtain of rock which terminated downwards in a jagged edge from which sheets of water were falling, and the effect of the daylight shining down the main opening was weird in the extreme. Now came the longest and most arduous part of the descent; gusts of wind caused by the falling water constantly buffeted the explorer, who, wet through to the skin, found his clothes extremely heavy and cold.

Eventually the bottom was reached, the ladder being just long enough to reach within a foot of the floor. On landing in a pool of water about 2 feet deep, and in a falling spray, it was with a feeling akin to consternation that on letting go of the ladder its lower end instantly rose to a height of some 7 feet from the floor, and it was not until one remembered that the weight of the next man would again bring it within reach, that the feeling of alarm was relieved. The light here was dim, but it was possible to see one's way about, and after walking out of the pool and the zone of falling water, four pistol shots were fired—the sign of a safe landing. The life-line was then set free and the signal given to haul up, so that the second man might be sent down.

Now followed a somewhat tedious period of waiting, sitting in semi-darkness with clothes saturated with water and a temperature of about 40° Fahrenheit. It was possible, however, to keep up the circulation by running to and fro over the floor of the cavern, which was covered, for the most part, by sand, while still keeping an eye on the ladder for the arrival of the second man.

At length, after about half an hour, the end of the ladder began to swing from side to side and gradually to come nearer and nearer to the floor, and then a figure could be seen slowly descending through the spray. He had a large pack upon his back, and the weight of this added to his own brought the ladder well within reach, and before he alighted care was taken to secure it strongly to a large boulder, which was lying in the pool.

Safely landed, the pack was opened, and found to contain two suits of dry clothing carefully wrapped in the waterproof covering in which we were wont to carry our sleeping bags. Having effected our change of clothing, we were now in a position to explore the cavern in which we found ourselves.

This was a large chamber over 100 feet in height and some 400 in length by 80 feet in width. The roof, so far as we could see, was composed of

PLATE X.—Cliffs and Terraces of Limestone.

a massive bed of limestone, but was not flat, as parts had fallen away. The shaft entered the chamber near its centre, which accounted for our being unable to see the walls of the lower parts of the shafts from above. At either end was a pile of stones and sand. The length of the chamber was from north to south, and on ascending the talus at its southern end we found a passage running in the same direction. This we were able to follow for a considerable distance, until eventually we were brought to a standstill by the passage becoming less than a foot in height. We calculated that at the farthest point reached we could not be very far from the end of the cave which led to our main camp, but as yet we had seen no trace of the stream, the passages being quite dry.

On returning to the foot of the shaft, we endeavoured to discover what became of the water, and found that it sank amongst the stones at the bottom of the pool. As we could find no other way out of the chamber, it was obvious that if we wished to trace the flow of this water we should again have to use fluorescein.

Before attempting to return we again packed up our dry clothing in the oil-skin cover and donned the wet ones. When we started on our exploration of the chamber we had left the life-line dangling at the foot of the ladder, and were now surprised to find that it had been hauled up. However, we signalled for it to be lowered, and soon saw an elongated cylindrical object being lowered down to us, spinning round as it came. This we found to be wrapped in several pairs of stockings, and on removing these to see what might be within were rewarded by finding a thermos flask filled with hot soup which one of our ever-thoughtful navy men had prepared for us.

Fortified by the nourishing contents of the flask, the ascent was commenced, and an extremely arduous undertaking it proved. The last man, after first securing the ladder to his waist-belt, had to cut the connections with the boulder, so that it might be possible to haul up the ladders on arrival at the surface. The ropes had shrunk somewhat owing to the fact that they had been hanging so long in the water, and on cutting the ties he was immediately lifted off his feet and carried several feet upwards, the ladder meanwhile swinging violently from side to side. Having secured a foothold on the ladder and unfastened the connection with his belt, he eventually reached the surface in safety.

The ladders were hauled up, and a quantity of fluorescein was put into the stream so that it might make its way underground during the night. The next evening saw us back at our main camp, and another period of waiting followed, during which a keen look-out was kept upon the springs.

On the third morning the water of our swimming pool was seen to be faintly coloured though the tint could not be detected in the shallower parts of the stream, but during the day the fluorescein came down in full force, thus proving the connection between Funnel Sink and the main cave. Thus the flow of water from Funnel Sink was seen to be parallel to that from Lake Sink to East Burn, both flowing in a direction 10° west of south.

The weather now changed completely, heavy rains falling almost every day, and the streams became swollen to such an extent as to render navigation very hazardous.

Under these circumstances we decided to postpone our departure for Lyell, although camp life had become decidedly unpleasant.

It was noticed that Blind Burn was now occupied by a stream, and as we hoped to prove a connection between this and the cave where we had sheltered from the thunderstorm on our first visit to the plateau, we once more climbed the escarpment armed with fluorescein.

We found the stream overflowing the Lake Sink and once more falling over the cliff near Thunder Cave. At the foot of the fall we introduced the fluorescein, and were able to trace it a few minutes later in the abyss of Thunder Cave, and within twelve hours it was seen in Blind Beck.

While on the plateau observations were made as to the direction of the joints in the limestone, and of these there were found to be two sets. One of these—by far the most persistent and well-marked—lay N. 10° E. to S. 10° W., the direction of the flow of the underground drainage, while the other and weaker set was approximately at right angles to this.

From these observations it was clear that the direction of flow of the underground waters was controlled by the direction of the master joints in the limestone, a conclusion which had previously been arrived at in other parts of the world.

At the end of the week, the storm having somewhat abated, we were able to set out for Lyell, and after some little trouble on account of the swollen state of the rivers, were able to return to our warm cabins on the steamer, and to the luxury of dry clothes.

CHAPTER XI

THE WINTER IN AND AROUND LYELL

Our next expedition was to be up the main stream of the Hutton River into the almost unknown region to the north, but as the winter was now upon us with its cold and rain, it was impossible to make a start until the early spring. On this account, we were obliged to spend the next two months in and around Lyell, but we were not, on that account, idle. There were our two bore-holes on the south side of the Permian escarpment to be visited, and the fossils which we brought back from the plateau country to the north-east also claimed our attention.

No reports had been received from the bore-holes for several weeks, but the latest news was that both were progressing favourably.

Considerable time was occupied during the first weeks after our return in making the preliminary arrangements for our trip into the far north, and we were most anxious to meet with some one who had visited the region. For several days we were unable to gain any information about the upper reaches of the river, but at last there came on board a rather wild-looking individual with a long unkempt red beard, and wearing a broad-brimmed felt hat, who stated that he had heard that we were inquiring for a guide. It appeared that he had made several trips up the river, and described an extensive plain beyond the limestone hills, with lakes and navigable streams, beyond which he had seen lofty snow-capped mountains. These he had never visited, but from his description we gathered that they formed a long range on both sides of the river.

He could tell us little of the nature of the rocks except that the plains consisted of red sandstones, and that some of the pebbles in the rivers contained what he took to be gold, but which on examination of some which he had brought away proved to be Iron Pyrites (FeS_2).

On one occasion when he had penetrated farther than usual in the direction of the snow mountains he had come upon a country covered by great spreads of gravel which he said were almost devoid of vegetation.

During the third week of our stay in Lyell, small earthquake shocks were felt, and the following night there was a faint red glow seen in the northern sky. The morning after, we found that our decks were covered with a fine gritty substance, which upon microscopic examination proved to be volcanic dust. From this we judged that somewhere in the interior volcanic activity was in progress, and we promised ourselves a full investigation at a later date.

Shortly after this the prospector we had left in charge of the bore-holes came into town and informed us that in B.H. 1 he had come upon rock salt, while in B.H. 2 there was a sudden change in the character of the rock at a depth of 630 feet, and that he wished us to take an early opportunity of inspecting the cores.

We therefore gave orders to get under steam in time for a start at daybreak, and sailed down the river to the spot where we had previously landed. Here we found that the banks had been carried away by the flood waters, owing to the heavy rains, and that the country was under water for a considerable distance from the river. It was, therefore, necessary to find another landing place, and, in consequence, we again headed up stream and landed a few miles south of the Permian outcrop, where the flood-plain was narrow and had not yet been submerged.

On landing we saw in front of us a steep-sided hill

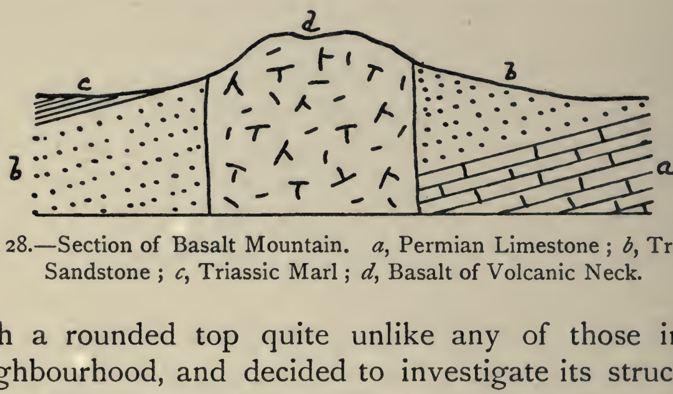

FIG. 28.—Section of Basalt Mountain. *a*, Permian Limestone ; *b*, Triassic Sandstone ; *c*, Triassic Marl ; *d*, Basalt of Volcanic Neck.

with a rounded top quite unlike any of those in its neighbourhood, and decided to investigate its structure. It was found to consist, so far as its lower slopes were concerned, of Keuper Sandstone, but its summit was of a hard compact basalt. From an examination of a section exposed in the banks of a small stream which flowed down the side of the hill, we concluded that this was a volcanic neck, the conduit of an ancient volcano which had become finally plugged by the solidification of the lava which filled it (Fig. 28).

The compact texture and durable nature of the basalt convinced us that it would make excellent road metal, and we were also able to dress it into square setts, suitable for paving the streets of a town.

As material of this kind had not previously been found near Lyell the streets of that town were in an anything but satisfactory condition, and for that reason we considered our discovery of considerable value, especially as it was not far from the river. We called the place Basalt Mountain, and decided, in the event of our other ventures in this neighbourhood proving successful, to construct light railways from B.H. 1 and B.H. 2, with a junction at Basalt Mountain, to the river bank, whence the products could be taken by river to Lyell, and also to Red River, Smithford, and Port Hutton.

At B.H. 1 we found the cores carefully arranged and were able from them to determine that at a depth of 120 feet from the surface there was a bed of rock-salt 35 feet thick, while the water pumped from the bore-hole contained a large quantity of salt in solution. Here was the possibility of an important industry, as all the salt in use in the country, both for domestic and manufacturing purposes, had up to the present been imported. We decided to order some powerful pumps, in order to estimate the supply of brine obtainable from the bore-hole, and also tanks for the evaporation of the liquid so as to obtain the salt in the solid state. This would, we considered, be a cheaper method of production than the actual mining of the solid rock-salt, as there was an abundance of wood fuel in the immediate neighbourhood.

Instructions were given to continue the boring, in order to ascertain if any further beds of rock-salt might be encountered at lower levels.

We next continued our journey to B.H. 2, where we found that the cores indicated the following section:

Feet.	
270	Keuper Sandstone.
360	Permian Limestone.
87	Brown Sandstone.
11	Black Shale with *Pterinopecten papyraceus.*
728	

The occurrence of the black shale with *Pterinopecten papyraceus* beneath a brown sandstone very similar to the Coal Hill Sandstone was very encouraging, as we should, in all probability, find the clay ironstone nodules and the "Top Seam" of Coal Hill, and boring operations were, therefore, at once recommenced.

It will be remembered that at Coal Hill 30 feet of grey shale intervened between the Pterinopecten Shale and the coal, and here at B.H. 2 the drill passed through 32 feet and then penetrated the coal.

We could ascertain little with regard to the quality of the seam, as the drill failed to bring up a core of the coal owing to its friability, but the thickness appeared to be the same as at Coal Hill.

Leaving instructions to continue the boring with the object of proving the "Bottom Seam," we now returned to B.H. 1, where we found that the drill had passed below the base of the marls and into the Keuper Sandstone, at a depth of 230 feet. As the occurrence of rock-salt is usually confined to the marls, it was considered useless to continue the bore to a greater depth, and we therefore started on the return journey to Lyell with the object of making arrangements to immediately set about the exploitation of the Coal, Salt, and Basalt.

On the way down to the river we made a rough survey of the route for the railway, and also selected a suitable site for a jetty to serve as a depot for the loading and discharging of the river steamers which would bring up the necessary machinery and, at a later stage, carry away the salt and coal.

On arrival at Lyell, we found that the Government had been considering the question of establishing a geological survey, and had unanimously decided to ask us to undertake a reconnaissance of the country to the north, with a view to our permanent employment, should we be willing, in the official survey department, when such should have been formed.

After some consideration, and having received an assurance that our free choice of route and general freedom of action would not in any way be affected by our acceptance of the Government appointment, we decided to accept it.

The fossils from the Carboniferous rocks of the plateau region to the north-east now engaged our attention. They had been identified and arranged by our palæontologist, who did not accompany us to the bore-holes, and he told us that those collected from the higher beds differed considerably from those near the base.

The Carboniferous Limestone of Western Europe has been very fully and carefully examined during the last few years, and what was formerly looked upon as a single and indivisible formation, has been separated into a number of zones.

In the first place it has been divided into two main sections, an older, known as the Tournaisian, and a newer, the Viséan. These are subdivided into the following zones by means of corals and brachiopods, each zone being characterized by an assemblage of fossils peculiar to itself. In each case a single species is taken as the index fossil of the assemblage, and its name is given to the zone:

5. Dibunophyllum zone.
4. Seminula zone.
3. Syringothyris zone.
2. Zaphrentis zone.
1. Cleistopora zone.

In England the Carboniferous Limestone rests on a very irregular floor of older rocks—an ancient land surface of hills and valleys. So we know that in that part of the world the Carboniferous Period was preceded by a time when the surface was above sea-level and was subject to ordinary denudation, possessing its brooks and rivers, though, of course, these ran in channels very different in direction from those of the present day.

In the extreme south of England and on the neighbouring coasts of Europe, this period immediately before the Carboniferous—the Devonian—was a marine period, and the waters of its sea appear to have spread slowly towards the north during the early part of the Carboniferous time.

Thus it happens that the lowest beds of the Carboniferous Limestone in the south of England are older than those in the north, a fact which was discovered by a comparison of their fossil contents.

Thus at Bristol all the five zones enumerated above are present, while in certain parts of the north of England the lowest beds belong to the Seminula zone.

The fossil remains have in this, as in many other instances, enabled geologists not only to determine the age of the rocks but to trace the geographical changes which took place during their formation.

The animals best suited for the zoning of rocks are the members of groups that were in rapid evolution during the time when the rocks were being formed, thus one group is chosen for one formation, a different one for another.

The Carboniferous Limestone has been zoned, as already stated, by means of the Corals and the Brachiopods, while in the case of the Lias, a much newer formation, the Ammonites were found to be the most suitable.

In a group of animals which are in rapid evolution, a given form will persist for but a short time, and will soon be replaced by another and usually more complex type. Such a form will, on this account, be found only in a thin series of beds, its modified descendants taking its place in the next series.

Some very interesting work has been done recently on the modifications which certain corals have undergone during the Carboniferous Period, and it has been shown that some of the forms in the higher beds are the direct descendants of other and somewhat different forms in the lower.

Fossils, when carefully studied, not only enable us to follow out the geographical changes which have occurred in the past, but sometimes also to determine the particular set of conditions which existed in different parts of a district at one and the same time.

Again referring to the Carboniferous Limestone of Britain, the fossils in one district indicate open sea conditions with coral reefs, while the fauna of another area indicates conditions such as those which occur in shallow lagoons similar to those which exist between barrier reefs and the coast.

So far as we could ascertain from our specimens the Lower Carboniferous fauna was very similar to that which occurs at the same horizon in the British area, and indicated in our case, by the abundance of its corals, open sea conditions.

The fauna of our lowest beds strongly resembled that of the Syringothyris zone of Britain, so it is probable that the oldest part of the Carboniferous is not represented in the area which we have examined.

Should we meet with these lower Carboniferous rocks in other parts of the country a comparison of their fossils may throw further light on this matter. So far, however, all we could say with certainty was that the junction with the underlying rocks was an unconformable one, that the upper surface of the underlying Silurian rocks was irregular and indicated an old land surface, and that the lowest beds of the Carboniferous appeared to be missing.

Our new official position allowed of our drawing upon Government stores, and we found that these included two steam launches, which would enable us to navigate the Upper Hutton more rapidly and with less fatigue than would have been the case had we had to depend on sails or paddles.

As then arranged, our party was to follow the main river to the limit of navigation for the launches, and there to establish a base camp which would be stored and kept supplied with provisions and other necessaries by one of the launches, while the other would remain there for use in case of emergency.

As we were now officials of the Government we could not, of course, be allowed to take up any mining claims, but as our discoveries of salt, coal, and basalt in the country south of the escarpment were made before our appointment, we were handsomely compensated for our interest in them, and were allowed to sell our land and the mineral rights to a company formed at Lyell, for a sum which covered all our expenses up to date, including the purchase of our steamer, and left each of us a good round sum in hand.

CHAPTER XII

THE CAMP FAULT AGAIN—LEAD ORE

THE season proved to be an early one, and we were able to make a start for the upper waters of the Hutton by the middle of March. The weather was still cold but fine and sunny, and the larger of the two launches being fitted with a comfortable cabin rendered us to some extent independent of the weather.

Having reached the point up to which we had previously explored the river, namely, its junction with East River, we landed and climbed a low hill on the tongue of land between the two streams. From this eminence, which we called Lookout Hill, we were able to obtain a clear view of a number of prominent points in the country to the north and north-east. As the published map did not extend far beyond Lyell we had to make our survey as we went along, and as a preliminary to this we took observations with our theodolite on a number of points which we had already visited, such as Brown Hill, the summit of White Mountain, a name which we had given to the high land behind Silurian Lake, a colliery chimney on Coal Hill, and the spire of Lyell Cathedral.

We then carefully determined the position of Lookout Hill by means of observations made with the theodolite

PLATE XI.—Limestone Cliffs.

on the altitude of several stars, and by comparing Lyell time, which we were still able to obtain with accuracy from the star shell which was fired into the air from Lyell Observatory every evening at 9 p.m., with the local time.

We also very carefully laid off a true north and south line across the flat top of the hill.

It was not our intention on the present expedition to attempt anything in the way of an accurate survey—that was to be left to others or to a later journey, when we should have more time at our disposal.

It was of considerable importance not only to ourselves but to the political party in power that our expedition should result in some pecuniary benefit to the State, as even before we left Lyell we heard rumours that a general election would probably take place at the end of the year, and that the existing Government had been accused of extravagance, one of the most criticized items of expenditure being the provision for this "new-fangled idea" of a geological survey.

What was the use of sending a costly expedition into the wild and mostly barren country to the north?—was asked by the opponents of the scheme. Was not the rich and fertile land between Lyell and the sea enough to support not only the present inhabitants but also any increased population which was likely to settle for many years to come?

It was therefore desirable that we should cover as much ground as possible, so as to get a general idea of the land and increase the probability of our happening upon something of value.

The first part of our journey lay between low banks of alluvium, with here and there a shallow gorge cut through the harder ganister beds of the coal measures, which were inclined here as elsewhere at angles of from 10° to 15° towards the south-west.

The ground became gradually more and more hilly, and the valley deeper and narrower, until eventually we entered the "Millstone Grit" country. Here there were many fine sections in the grits and shales, the latter being in several instances fossiliferous. We stayed here as short a time as possible, as there was not likely to be anything of economic importance; but we had one good day collecting fossils from the shales while a fresh supply of wood for the furnaces of our launches was being obtained. The fossils were of a distinctly marine type, showing that the shales were laid down in a shallow sea, the coarse sandstones which alternated with them indicating the proximity of land at the time of their formation.

We were now nearing the line of the Camp Fault, and we therefore kept a sharp look-out for it, in order to see whether it extended to this valley and to ascertain if possible its exact nature.

Having reached a point which we judged to be about four miles from the line of the fault, we noticed that there was a change in the direction of the dip. We passed through a gorge in which was exposed a fine section of an anticlinal fold, the dip changing from south-west to north-east, and increasing gradually to 25°. Shortly after passing the anticlinal axis we came upon two seams of coal, the upper one of which proved to be the Top Coal of Coal Hill, the black shale with *Pterinopecten papyraceus* occurring in its usual position above it. Less than one mile from the outcrop, the line of the Camp Fault was crossed, and we found ourselves once more on the Carboniferous Limestone. Thus this new coal-field was extremely narrow, but we determined to land, and if possible map its lateral extension along the line of the fault. Two days' work sufficed to show that the field was quite small, having a total extension of three and a half miles from north-west to south-east, and a maximum breadth at right angles to this of one and a quarter miles.

As the coal seams only occurred over a portion of this area and the coal was of poor quality, the field was evidently of little value.

The great fault now claimed our attention, and we were much disappointed to find that there was not a clear section of it in the valley of the main river. Just after entering the coal-field, however, we had passed the mouth of a small tributary which, judging from the amount of foam upon its surface, had recently flowed over a steep and rocky bed. This was more likely to yield a clear section than the wider and less steep valley of the Hutton.

Entering the tributary valley, we found ourselves in a beautiful glade with many magnificent pine trees, but this rapidly narrowed, and we came to the mouth of a cañon, which we ascended by means of a canoe for a distance of about half a mile. The sides of the cañon were vertical, and yielded fine sections of the ganister beds.

After negotiating two rather dangerous rapids, we were eventually able to effect a landing, and to scramble along ledges of rock and over large fallen blocks, until we reached the line of the fault. The gorge was now some 250 feet deep, and on the vertical face on the opposite side of the stream we saw on our left the Carboniferous Limestone, and on our right the Coal Measures, with their two seams of Coal. Between the two lay about 30 feet of crushed and broken "fault rock," the line of the fracture being inclined at an angle of 75° to the right. The Coal Measures were bent upwards near the line of fault, as though torn and frayed against the surface of movement (Fig. 29).

Having returned to the main stream, and again

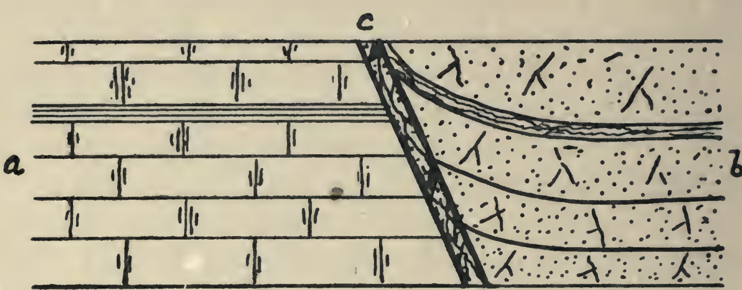

FIG. 29.—*a*, Carboniferous Limestone ; *b*, Coal Measures ; *c*, Fault with fault-rock.

crossed the fault, we entered upon a region of magnificent scenery. On either hand the limestones rose terrace above terrace for several hundreds of feet, while the dark openings of numerous caverns were to be seen along the top line of the dazzling white screes which fringed the face of each gigantic step (Plates X. and XI.).

In several places long vertical rifts or chimneys cut through the terraces ; they were evidently due to the weathering out of some material less resistant than the massive limestone beds. So persistent was this feature that we decided to land and make a closer examination.

Selecting a fissure about 12 feet in width, we proceeded to clear away the earth and stones which encumbered its mouth. This we found a more arduous and dangerous task than we had anticipated, as on disturbing the material a quantity of loose scree was brought down from above. We therefore changed our tactics, and introduced three dynamite cartridges, and having attached detonators with a long length of fuse to each, applied a light and moved off to a safe distance.

Having listened carefully in order to be sure that all the cartridges had exploded, we returned to the foot of the chimney and found that most of the weathered material had been scattered far and wide over the meadow, and that much of the upper part of the scree had slipped down to fill its place, thus leaving bare a face of the material in which the chimney was excavated. An examination of the freshly-fallen blocks showed them to consist of a mixture of Crystalline calcite ($CaCO_3$), and Barytes or heavy-spur ($BaSO_4$), with numerous masses of galena, a Sulphide of lead (PbS), and crystals of Zinc blende (ZnS). On washing the finer earthy material displaced by the explosion, it proved to contain large quantities of galena and blende, and as these are the principal ores of lead and zinc respectively, we seemed to have struck a valuable find, and one which might well repay further investigation.

A stay of several days in this locality was indicated, and as the weather was now decidedly warmer, and our quarters on the launch somewhat cramped, a couple of tents were pitched near the bank of the river, and we proceeded with our investigation.

Several other chimneys were examined, but most of them proved to contain only very small quantities of ore, and on further investigation it became rather doubtful if our original find would pay the expenses of working.

Before leaving the locality it seemed well to climb to the top of the uppermost terrace, to get as wide a view as possible of our surroundings. To reach the top, however, we found to be no easy matter. Everywhere the screes seemed to be topped by an almost vertical face of limestone which was so rotten as to render climbing extremely dangerous, if not impossible. The chimneys were worse than the open faces, as the vein-stone was in an even more friable condition than the limestone, and further they were filled for the most part with fine screes, which commenced to run as soon as they were disturbed by the feet. At last a wider and deeper scree was found, which obliterated at least three of the terraces, and appeared to run farther back into the hill than the others. This we climbed with difficulty to a height of 300 feet above the river, and found it to be held together to some extent by small bushes of various kinds which had found a root-hold between the fragments. At its upper end the scree proceeded from a chimney similar to those we had examined below, but running in a different direction, cutting the cliff obliquely to its face. Entering this gulley we found ourselves in a great rift-like opening with walls of limestone some 30 feet in height, and closed at its upper end by a moss-grown scree reaching to the summit. This we climbed and emerged on the plateau, from which we had a fine view of White Mountain. The surface of the plateau consisted of bare limestone clints, but the line of the gulley up which we had climbed was continued for miles across country as a lane of greensward with many beautiful ferns.

With much labour a tent was brought up from below, and we established ourselves in the upper part of the gulley in a sheltered nook, and then sent down for picks and shovels, determined to investigate the cause of the gulley, and of the grassy lane above. To this investigation we were instigated by the discovery near the tent of several large fragments of galena.

Doubtless the vertical face behind the moss-clad scree at the head of the gulley would be the easiest to attack, but as we had already had a somewhat unpleasant experience of these screes when disturbed, we decided to sink a pit on the line of the lane.

At the end of the first day's work we had a hole 6 feet square and 8 feet deep, and had passed through 3 feet of rich reddish brown soil, and 5 feet of angular gravel, consisting of small pieces of limestone, masses of white, and pink, and yellow calcite, and some small cubes of galena. The bottom of the gravel had not been reached, and as the labour of throwing out the material increased rapidly with increase of depth, and as the sides of the pit showed an inclination to collapse, we stopped the work until such time as we could obtain some hoisting tackle from the launch, and cut down some pine trees to serve as a lining for our shaft.

This cutting down of the trees and sawing them into lengths occupied the men for several days, during which we made an examination of the plateau. We were able to trace two sets of mineral veins across its surface by means of the grassy "lanes" which they formed, namely, one set of narrow veins running east and west, to which the one where we had used the dynamite belonged, and another set represented, so far as we could see, by two much wider veins, the one in which our shaft was being dug, and another, 600 yards away, and of the same width, 30 feet. The trend of this latter set was south 10° east.

On the surface of the plateau between the two large veins was a curious circular hollow with a flat floor some 10 feet below the general surface. It was 60 feet in diameter, and overgrown by small bushes. It suggested an abandoned water sink, and much tempted us to further investigation, but as our business on this expedition was economic geology, we decided to leave it, at all events until we had completed our prospecting of the mineral veins.

Being informed that a sufficiency of poles had been cut, and that all was ready for transporting them to the plateau, we rejoined our men on the river bank, as all hands would be required. The work of hauling the logs up the scree was heavy in the extreme, and occupied three days, after which we decided to give all hands two days' rest, and returned to the riverside camp, as that was the more comfortable.

Back on the plateau, we rigged a small windlass above the shaft, timbered the sides, and then continued the excavation.

The spoil was hoisted out in a large wooden box made for the purpose.

At a depth of 12 feet from the surface the material became coarser, and many of the larger blocks of calcite had to be broken up with a pick before they could be placed in the box.

A depth of 14 feet had been reached, and the box had just been lowered when we were startled by a cry from one of the two men working below, and on climbing down the timbers, found that a boulder larger than usual had been encountered, and that when struck with the pick it had flown into fragments, covering the entire floor of the shaft with glittering cubes of galena. This substance possesses a cleavage parallel to the faces of a cube and splits most readily along these planes. The mass, which weighed not less than one hundred and twenty pounds, had been originally crusted over with clay, and when struck had broken along the cleavage planes revealing the glittering surfaces within.

The fragments were soon hoisted to the surface for examination, and the mineralogist of the party having filled his pockets with the mineral, set out for the launch, where the assaying apparatus had been left, in order to make an analysis.

The work now progressed rapidly, as every one was anxious to get to the bed rock which was capable of yielding such rich finds.

Several other large masses were sent up in quick succession, and at the end of the day bed rock was reported.

Early next morning work was resumed, and soon the rock floor had been cleared of débris from side to side.

A broom was then made of heather, the surface swept clean, and we descended for an examination. The find proved richer than we had supposed it to be. The pit, which had been sunk in the centre of the lane, was 8 feet square. Across its centre was a vein of pure galena 3 feet wide, and this was flanked on either side by calcite with thin strings of the ore running through it, parallel to the main vein.

There was no sign of zinc blende and no barytes, but the value of the lead ore alone would, if it proved on further investigation to be continuous, be enormous.

On returning to the valley laden with as much of the galena as we could carry, we were met by the mineralogist, usually the quietest man of our party, but now evidently labouring under suppressed excitement.

So long as the men were within hearing he would say nothing as to the result of his investigations, but as soon as we were alone he told us that unless he was mistaken the galena contained nearly five per cent. of silver. This would render the vein highly profitable for the silver alone, and further work on the fresh samples which we had brought down with us fully confirmed his original assay.

Investigation on the plateau showed that the narrow east and west veins carrying galena and blende were of later date than the two large ones with galena only, which were cut by them.

Having discovered mineral wealth sufficient to cover the cost of our expedition one hundred times over, we felt justified in spending a little time in the investigation of the curious circular hollow which we had seen between the two large veins, and as the tools were still on the plateau the present seemed a suitable opportunity.

The crew of the smaller launch, who had been away collecting firewood, knew nothing of our discoveries, and on their return we at once dispatched them to Lyell with a private note to the Premier, informing him of our discovery and suggesting that he should send up a party to open up the mine. As we thought he might wish to keep the knowledge in the hands of the Government for the present, we were careful that no communication was held between the crew of the launch and our men on shore, the former supposing that they were sent down for a further supply of provisions, rendered necessary by our prolonged stay on the plateau.

The circular pit proved on investigation to be filled with fine sands and clays, which we penetrated to a depth of 16 feet, when we came upon a layer of red earth, similar to that with which we were already familiar as occurring in the caves beneath the plateau.

Beneath this "cave earth" we found numerous gigantic bones which appeared to have belonged to one of the large extinct elephants. So far as we could judge from the bones obtained from the first trial shaft, this was the Mammoth (*Elephas primigenius*), which lived during the cold Pleistocene Period.

In a long trench which we had made we later discovered several teeth, which confirmed our previous determination of the other bones.

The pit would appear to have been a sink hole, formed on the plateau in pre-Pleistocene times, which had become choked up by fallen blocks and earth. Into this pit the unfortunate mammoth must have fallen, and being unable to climb out, have eventually been buried by the Pleistocene sands and clays.

The bones obtained were carefully preserved, in the hopes that we should be able one day to return and dig out the remainder of the skeleton, so as to be able to set it up in the National Museum at Lyell.

The launch being now due back from Lyell, we set about striking the upper camp and transporting our tools to the riverside, in readiness to continue our journey.

Two days passed without any sign of our boat, but on the third morning after our return to Riverside Camp we were startled by the hooting of a siren. As our boat carried an ordinary whistle we knew this must proceed from some strange craft. We thought at first that this might be some rival prospecting party, but were relieved to see rounding the bend below the camp our provision boat closely followed by the graceful form of the Premier's private launch, to which she was acting as pilot.

It appeared that on receiving our report the Premier had decided to visit the vein in person, and had kept our party back in order that the smaller launch might act as pilot to the larger, the commander of the latter not having previously navigated these waters.

The Premier's journey, he informed us, was ostensibly undertaken for purposes of sport, and after satisfying himself by a personal inspection that we had not over-estimated the value of our find, he decided to keep the discovery private for the present.

He informed us that the Opposition outcry with regard to our expedition was increasing, and the matter threatened to become one of the chief questions at the elections. Under these circumstances, he hoped by holding up all information as to the results until a few days before the contest, and then breaking the news at an opportune moment, to secure the re-election of the Progressive party.

That evening we dined with the Premier on his launch, and the next morning at daybreak once more sailed northwards.

CHAPTER XIII

THE LAKE FAULT—OIL—GOLD

THE foliage of the trees which fringed the river and occupied the lower slopes of the neighbouring hills rendered it somewhat difficult to see the structure of the country, but by landing from time to time we were able to ascertain that we were still in the limestone area. There followed a tract of woodland country many miles in width in which there were no exposures of the solid rock anywhere in the neighbourhood of the stream, and the river meandered considerably. Then the valley once more narrowed and we entered a gorge, the sides of which consisted of dull-grey grits and shales with a few layers of black Carbonaceous shales in which we found numerous graptolites belonging to the genera *Monograptus*, *Cyrtograptus*, and *Rastrites*, from which we knew the rocks to be of Silurian age. It was probable, therefore, that we had crossed the line of the Lake Fault, the second of the great dislocations affecting the plateau area.

Being anxious to locate the fault line as closely as possible, we landed to explore the surrounding country, and seeing that a tributary stream was so useful to us in the case of the Camp Fault, we followed the banks of a small river which came in from the east. For several miles from the Hutton the stream flowed through pine woods, then the ascent became steeper, and soon exposures of shale containing Carboniferous corals were seen. These shales were doubtless the cause of the open nature of the country and the broad valley of the Hutton, as they were soft and easily weathered.

The dip of the shales was 20° down stream, that is away from the supposed line of the fault, which we had evidently not yet crossed as we were still on Carboniferous Rocks. In the next section the dip was still in the same direction but had increased to 45°, a change which warned us that we were probably near the fault and that we must keep a sharp look-out if we were to locate its line exactly.

The stream now widened, became shallow, and was joined by a small tributary which flowed over the Carboniferous shales. Immediately above the junction of the two streams the water fell over a wall of rock that, at first sight, looked like a dyke of igneous rock, which, cutting across the stream course, formed a barrier.

This wall of rock, however, appeared on closer examination to consist of angular and polished fragments of Silurian grits with a few smaller ones of limestone, the whole being cemented together by a porcelain-like substance, which often showed striations. This was, in fact, the fault rock on the actual line of dislocation, and was immediately succeeded by grits of Silurian age, which could be seen in the bed of the stream within 20 feet of the exposure of Carboniferous shales in the tributary.

Pursuing our journey up the main stream, the hilly country soon came to an end and we entered an undulating plain the vegetation of which was of the parkland type—long stretches of grass-land with clumps of trees at intervals upon its surface.

At the point where we left the mountains we also left the Silurian rocks, which in their last exposure were seen to be dipping steeply to the south-west.

The next rock exposed was a red and green marl with pseudomorphs after rock-salt and also numerous lenticular masses of gypsum. On some of the bedding planes were minute fossils which on examination with a lens turned out to be the small crustacean *Estheria minuta.* The rocks were evidently Triassic. They dipped at 10° towards the north, and were therefore unconformable with the Silurians upon which they rested.

The Trias was succeeded conformably by brown earthy clays with thin bands of bluish-grey limestone, and some thick shales. All these beds contained numerous fossils, amongst which ammonites were the most conspicuous. They were of Lower Jurassic age, and were the first rocks belonging to that formation which we had seen in this country. They were followed by a thick series of oolitic limestones, porous sandstones, clays and calcareous grits, which were visible in numerous detached sections along the river.

The dips were in some places towards the north and in others towards the south, but always of a low angle not exceeding 15°. There was no indication of faulting or of other violent disturbance of the beds, and from these facts we concluded that the rocks were folded into a gentle set of symmetrical anticlines and synclines. After several days' journeying through this fertile region, which appeared to stretch to the horizon in all directions, we noticed some more broken ground forming a low range of hills to the east of the river.

The broken ground seemed to offer better facilities for the study of the structure of the plain than did the small and scattered sections along the river, so a visit to it was decided upon.

The same alternations of clays, limestones, and sandstones were encountered but were much better exposed. On entering one of the numerous valleys of this rough part of the territory on a close summer afternoon we noticed a strong odour of petroleum, and upon investigation found that a dark brown sandstone in which the valley was cut contained a considerable amount of tarry matter, from which the odour arose.

In many parts of the world oil occurs in rocks of this age, and in nearly all cases the wells are situated on or near the axes of the anticlinal folds, in the rocks of which the petroleum seems to collect.

The brown sandstone would appear to have been an oil-bearing bed from which the cover of overlying rocks had been denuded, and from which the oil had in consequence escaped. Should we be able to tap the same or similar rocks beneath a clay or shale cover in one of the neighbouring anticlines, there would be a considerable probability of our finding a supply of oil or of natural gas.

We had not, of course, the boring apparatus necessary for actually testing the capabilities of this field, and we could not, therefore, do more than locate the various anticlines and thus indicate the lines for future research.

The location of the anticlines in this flat country with few exposures was by no means an easy matter, as many of the beds of rock strongly resembled one another.

We were able, however, to separate the rocks into three groups, which we may call respectively the Lower, Middle, and Upper Jurassic, though without further work on the fossils we could not definitely state that these agreed with the similarly named divisions of Western Europe.

It was near the base of the middle division that the brown tarry sandstone occurred, so that any part of the area where the surface consisted of the Upper Jurassic, or the upper part of the Middle Jurassic, might prove worthy of attention.

Each of the three groups of rocks contained characteristic fossils, which could be readily identified in the field, and this made our work easier. Without them it would indeed have been well-nigh impossible.

The denudation which had taken place amongst these rocks had not been very severe, and as a result the tributary streams flowing along the strike of the folds still occupied the synclinal hollows, while the higher ground forming the subsidiary water-sheds lay along the anticlinals. This fact enabled us to locate two of the anticlinal axes in both of which the surface layer consisted of the lowest bed of the Upper Jurassic, from which we might conclude that the whole of the oil-bearing series would be found below. The positions and directions of these two lines were carefully determined and recorded upon the rough map which we were preparing as we went along.

Ahead of us as we once more sailed up the river, we could now see a range of lofty mountains on the summits of some of which snow still clung, though it was now the end of May.

As the edge of the plain was approached, we again crossed an outcrop of the Lower Jurassic, and finally entered upon a belt of Triassic Marls dipping in this instance towards the south. The Triassic and Jurassic rocks, therefore, formed a syncline with minor undulations within it.

The Trias outcrop was much obscured by great spreads of sand which had been brought down by the river from the valley above. An examination of the sand showed it to consist chiefly of quartz grains, angular in character and similar to those derived from the waste of a granite or similar rock, with a few fragments of felspar and a little magnetite and mica.

Entering the mouth of the valley, we found our further passage barred by rapids, and had, therefore, to resign ourselves for the future to the slower progress of canoes; luckily the ground on both sides of the river was fairly open, so that we were not unduly hampered by trees or undergrowth in the portages, which we had to make from time to time.

We now set about the establishment of our base camp, and, this being completed and the canoes provisioned, we started on what would probably be the final stage of our journey.

The slower mode of progression imposed upon us by the use of canoes in place of the launch was not without its advantages, as it enabled us to make a fuller and more detailed survey. The structure of the country now became very complicated. Lofty mountains towered on either hand, the dip of the strata was very steep, and the rocks were frequently cleaved and crumpled.

The Trias, as on the south side of the plain, rested unconformably on rocks of Silurian age, in this instance a grey slaty rock with very few fossils. The dip was now towards the south, and varied from 50° to 80°. Sections were plentiful in the rugged country, which fact alone rendered possible the unravelling of the complex structures.

The Silurian slates were found to be resting upon grey grits with Ordovician fossils—the Ordovician was the oldest formation we had yet encountered, and it was followed by other beds which from the presence of trilobites of the genus *Paradoxides* we concluded to be Cambrian, the oldest fossiliferous series.

The dip of the rocks increased in steepness as we ascended the valley, and in the Cambrian outcrop reached 60°. The bedding of the Cambrian rocks was rather confused, but there appeared to be an anticlinal fold near the middle of the outcrop.

Following the stream, we again reached Ordovician rocks, but the dip still appeared to be towards the south, and in one section the Cambrian beds could be seen resting on the Ordovician. This was clearly a case of inversion of the beds caused by over-folding as seen in Fig. 30. The Ordovicians were found to rest upon Silurians a little farther up stream, a fact which confirmed the view that the rocks were over-folded.

In the Silurian outcrop there was a reversed fault, which had the effect of repeating some of the beds. After passing this fault, we crossed the denuded surface of another overturned anticline, the rocks being met with in the following order—Silurian, Ordovician, Cambrian, Ordovician, Silurian.

The last named was not visible in the river-bed, but occurred as a small inlier at the foot of a great escarpment to the east of the river.

At the foot of this escarpment, which was nearly 2000 feet in height, there was a sudden and complete change in the nature of the rocks. The Silurian beds could be seen resting on a mass of material which was

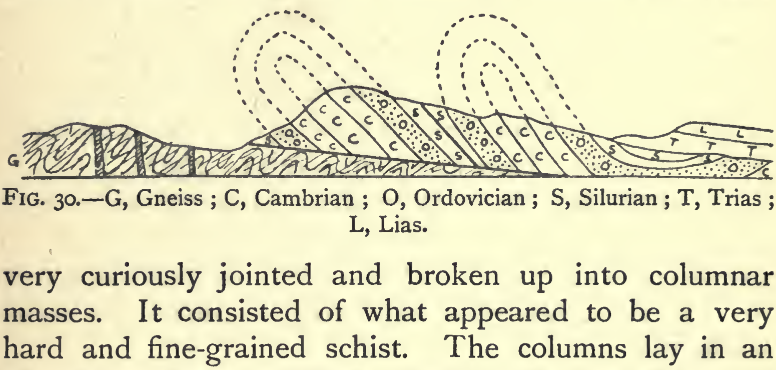

FIG. 30.—G, Gneiss ; C, Cambrian ; O, Ordovician ; S, Silurian ; T, Trias ; L, Lias.

very curiously jointed and broken up into columnar masses. It consisted of what appeared to be a very hard and fine-grained schist. The columns lay in an almost horizontal position, dipping at about 7° or 8° towards the south, in which direction their axes lay. Their surfaces were curiously grooved and striated, in fact, so regular were some of these masses that they resembled stone mullions (Plate XII.). This structure pointed to the existence of a fault or other dislocation running along the foot of the hills, and since the plane of fracture, as indicated by the lie of the mullions, was nearly horizontal, it must be in the nature of a thrust-plane.

These great thrust-planes, or overthrust faults, as they are sometimes called, occur in many mountainous regions, and are the ultimate result of the great thrusting and crumpling movements of the Earth's crust to which the mountains themselves are due.

The mass of country above the thrust-plane had, in some instances, been pushed forward over the rocks below for a distance of several miles, and the mullion structure was due to the tearing-up and shredding-out of the rocks along the line of contact of the moving masses. They were, in fact, slickenside on an enormous scale.

In the present instance it was impossible without a very full and minute survey of the whole region to discover the amount of displacement due to the thrust, but it was clear from the lie of the rocks that the movement of the overlying mass was from south to north.

Beneath the thrust-plane was a hard crystalline rock which at first sight resembled granite, but a more careful examination showed it to have a very different structure to that rock, although consisting of much the same minerals.

Grains of quartz, felspar, and mica were present, but they were arranged in thin layers, not flat like bedding-planes in sedimentary rocks, but curved and undulating as though they had been produced by the materials flowing while in a treacly condition.

This rock is called gneiss, and may have been produced from granite by intense crushing and shearing.

There were also some darker masses possessing a similar structure and containing large quantities of the mineral hornblende, and these may have been produced from igneous rocks such as gabbro, or some other basic rock.

The changes which are brought about by the action of pressure and shearing are partly physical, resulting in the development of new structures, such as the banding or "foliation" described above, and partly chemical, resulting in the production of new minerals. The changes are summed up under the term metamorphism, and the materials which have undergone such changes are spoken of as metamorphic rocks.

From their general appearance and their position with regard to the Older Palæozoic rocks above the thrust-plane, we concluded that these rocks belonged to the Archæan group, the oldest known rocks.

There were in addition to the coarse-grained gneisses certain finer-grained rocks in the complex. These possessed a structure somewhat similar to that of the gneisses, but the folia were thinner. They are called schists, and were of several different kinds. One kind in which mica and quartz are the principal constituents is called mica schist, and has in all probability been formed by the metamorphism of ancient sediments, such as micaceous sandstones or grits.

Another kind occurred in long narrow bands traversing the granitoid gneisses from north-west to south-east, and consisted of a dark olive-green mineral, chlorite.

These are chlorite schists, and may have been formed from dykes of basalt or of dolerite, which were intruded into the great igneous complex before the metamorphic forces came into play.

There were also to be seen dykes of dolerite and basalt of a later date, which ran nearly at right angles to the older set and were unaffected by any metamorphic changes.

In one place was a clear section of the great thrust-plane, and the gneisses could be seen beneath it, the later basalt dykes being cut off by the thrust. Thus clearly the forces which produced the metamorphism were not the same as those which caused the thrust-plane, the sequence of events having been—

(*a*) Formation of the igneous complex of granites, gabbros, and of the ancient sediments with dykes of dolerite or basalt.
(*b*) Metamorphism of the above to form the gneisses and schists.
(*c*) Intrusion of the later basalt dykes.
(*d*) Production of the thrust-plane.

The ancient crystalline rocks are often very rich in minerals, and it therefore behoved us to keep a sharp look-out for signs of anything of value.

An examination of the river to the north of the thrust-plane showed that it divided into three branches, none of which was likely to prove navigable. They were very rapid, and appeared to carry a large amount of gravelly matter, which they were depositing in huge spreads and terraces before entering the open valley up which we had travelled.

The fact that the rivers were no longer navigable necessitated our travelling on foot as, of course, no horses were available in these wilds, and indeed in many parts the country was so rough that they could scarcely have travelled.

Accordingly a camp was established near the parting of the streams and called Three Forks Camp, the canoes being sent back to the base camp for a further stock of provisions.

While waiting for these we set to work to examine the sand and gravel brought down by the three streams, as the nature of these deposits would give a clue to the kind of rocks to be expected in the upper parts of their valleys.

The stream from the east was found to be carrying much dark-coloured matter, and to be forming deposits of black sand with a number of greenish grains. The chief material appeared to be magnetite, an oxide of iron (Fe_3O_4), but as there was not sufficient to render the deposit of commercial value, we paid little attention to it beyond coming to the conclusion that somewhere in the higher parts of East Valley there must be basalts or other similar rocks.

The deposits in Centre Valley appeared still less interesting. They consisted of yellow quartz-sand, very fine grained and well rounded, and evidently derived from the waste of the granitoid gneiss.

The work on these sands led to some talk about gold-prospecting and the process known as panning-out, and as only one of us had ever carried out this process, we went down to the river bank in Centre Valley, in order that he might give us a demonstration.

We took with us an iron wash basin from the camp, and arrived at a point where there happened to be a natural section in the sandy alluvium, settled down in the warm afternoon sun for our lesson in panning.

For the purposes of the demonstration a small bag of the heavy black sand from East Valley had been brought, and a little of this was mixed with a larger quantity of the quartz sand in the wash basin, which was then filled up with water. By giving to the basin a partly rotatory and partly oscillating motion our instructor got the water into sufficiently rapid motion to hold some of the quartz grains in suspension, and these he washed out of the bowl by allowing part of the water to spill over and carry the suspended grains with it. By repeating the process with a fresh supply of water more quartz was carried over, and so the magnetite, too heavy to be held in suspension, unless on very violent movement of the water, was gradually concentrated at the bottom of the bowl. It was not possible to get rid of all the quartz in this manner, nor yet to retain the whole of the magnetite, but it was explained that, gold being much heavier than magnetite, its separation was easier and more likely to be complete.

We thought it would be a good thing to practise this, and so, having procured another basin, two of us set to work under the supervision of the old hand. The fourth man, "the troglodyte," said the afternoon was too fine to be wasted in such frivolity, and so, after a dip in the stream, fell asleep over a pipe.

Having to some extent acquired the knack of handling the pan, we were determined that the troglodyte should have his turn at the work, and so, having set him to work, walked up the river bank to seek the best track up the valley for our next journey.

We had been away not more than a quarter of an hour when we were startled by hearing a number of pistol shots in rapid succession. We stopped for a moment to examine our automatics, and then rushed off

PLATE XII.—Photograph of "Mullion" from Thrust-plane.

at full speed to the place where we had left our friend. On rounding a bend of the stream we were relieved, but somewhat mystified, to see the troglodyte on the top of a bank of sand waving his arms frantically and shouting something to us, which we were unable to hear properly owing to the roar of the torrent. However, he appeared to be quite safe and sound, at all events in body, so we put up our pistols and slackened our pace.

He had rushed back to the place where we had left him at work, and we followed more slowly. Presently, as we got nearer, he showed his head above the bank, and shouting one word, "Gold!" again disappeared.

Thinking this was a stupid hoax, we determined to return to camp, and then thinking it would be as well to give him a ducking by way of revenge, we went to the sandpit. There we found him sitting on the bank, working away vigorously with one of the pans. Not being expert at the work he had splashed himself from head to foot with water, and only paused for a moment to point to the other bowl which lay near. Our expert panner made a dive for this, and after holding it to the light of the setting sun, said calmly, "Gold it is right enough." In the bottom of the pan, clinging to the still wet surface, was a faint yellow smear, the "colour" of the prospector.

There was now little daylight remaining, but the expert at once set to work upon another lot of sand and once more got the colour, but this time so distinctly that there could be no shadow of doubt about the discovery. We could do no more that day, as the light had gone, so we started for camp, some three miles away.

On the way in, the troglodyte told us that after we had left him, he had the misfortune to drop the small bag of black sand into the river, and so decided to practise the motion with ordinary sand. This he continued to do for some time, and finally, in an absent-minded way, was washing out the residue as slowly as possible, so as to practise control of the movement, when the sunlight happened to strike the edge of the little heap of wet sand in the bowl and he noticed a thin yellow line along its edge. Carefully continuing the process he succeeded in getting rid of nearly all the sand, and examining the "colour" with a lens was satisfied as to its nature. We had missed the gold in the first instance by introducing the black sand, which, at the end of the operation, was left in sufficient quantity to mask the metal.

Needless to say we were up before the sun next morning and at work at our digging as soon as the light was strong enough, for although we had proved the presence of gold, we had not yet ascertained whether it was present in paying quantity.

The accumulation of gold by stream action is similar in principle to the process of panning. The lighter quartz sand is swept away, while the heavy gold collects in pockets or hollows of the stream bed. It very frequently happens that the richest part of a deposit, such as we had been examining, lies at the bottom where the sands are in contact with the bed rock, and we therefore set to work to dig down to this level.

The gold in this case would appear to have been disseminated through the mass of the gneiss, and as this was slowly worn away by the agents of denudation, the stream had panned out the dust and accumulated it in these gravel-filled hollows. In the course of the excavation we came across several layers of small gravel, made up, for the most part, of pebbles of quartz larger than any crystals of quartz which we had seen in the gneiss, and from this we judged that somewhere up-stream were veins of quartz, which might or might not be gold-bearing.

After a week's hard work the bottom of the deposit was reached, the lowest layer of sand was found to be much richer than those previously examined, and we were able to obtain upwards of four ounces of dust from it as the result of one day's work with our two camp basins.

The floor on which the sand rested was of gneiss, and was fairly regular, but at one corner of the trench it seemed to fall away rather rapidly to a lower level. This hollow might prove worthy of exploration, and we commenced to work the trench in that direction, and found a hollow in the rock surface filled with gravel consisting of the white quartz pebbles which we had noticed at higher levels. There was one small pocket measuring not more than 5 feet by 3 feet, and having a depth of 4 feet in its deepest part. This was completely filled with gravel, the whole being buried beneath the gold-bearing sands. We decided to make a thorough examination of the contents of this hollow, and were well rewarded for our trouble.

One of the first pebbles to be examined was found to contain particles of gold, and near the bottom we came upon a number of nuggets, the largest of which weighed just over two ounces, the others ranging down to the size of a small pea. In all, from this single cavity, we extracted seventeen ounces of gold.

Continuing our researches we made numerous other trenches at intervals in the Centre Valley, and everywhere came across traces of gold in the sands, though we did not find any more rich gravel pockets. Such doubtless existed beneath the great spreads of sand, but only systematic mining could bring them to light. Before it would be possible to work the sands at a profit it would be necessary to establish proper separating plant, and to adopt hydraulic mining.

We had still the other two valleys to explore, and here also we might find gold-bearing rocks, as they both appeared to flow from the gneiss mountains.

For several days past we had noticed a curious-looking grey cloud away on the western horizon, but had been so engrossed in our gold-mining operations that we had paid little attention to it. One evening, while talking over our plans and deciding whether East Valley or West Valley should next claim our attention, we were interrupted by a curious throbbing vibration of the air, hardly as yet a sound, but very disquieting in its effect.

While we were debating as to its cause it increased until it resembled the muttering of distant thunder, which was later replaced by a sound like the discharge of heavy artillery. This eventually became an almost continuous roar, and at about midnight the western sky became a lurid red, lit up every few seconds by bright flashes of orange yellow light. As we could feel slight tremors of the ground at the same time, there was no doubt in our minds that somewhere to the west of us a volcano was in eruption, and this decided us in favour of West Valley, so that we might have an opportunity of investigating the phenomenon.

CHAPTER XIV

EXPLORATION OF WEST VALLEY—A VOLCANIC ERUPTION

Now commenced the first extensive journey we had made on foot, and considerable care was necessary in choosing the most portable form of food. The food difficulty was to some extent lessened by the fact that wild sheep were to be found in considerable numbers amongst the hills. These animals, though shy, were not very active, and we usually found little difficulty in bringing one down when we required a supply of fresh meat.

We carried our sleeping-bags, but dispensed with the tent, as the weather was fine and warm.

The gravels of Three Forks were found to occur at intervals over the first forty miles of West Valley, and in several instances yielded small quantities of gold.

As we had no time for excavation, we were unable to ascertain if the gravels from which the nuggets were obtained occurred in this valley also, but this seemed unlikely, as there were few, if any, of the white quartz pebbles, such as we had seen in Centre Valley Stream. The country consisted of gneiss, traversed by numerous dykes of several different kinds of igneous rock.

During the first four days we could still hear the explosions of the volcano, but they were gradually diminishing in frequency and violence, the crisis having evidently occurred on the night before we left Three Forks, and we began to fear that we had lost our chance of witnessing the eruption. The sounds, however, continued at intervals throughout the next day, and did not appear to diminish any further, while the sky was still illumined at night.

Arrived at a fork in the stream where the two branches appeared to run at right angles to each other, we were undecided which was most likely to lead us to our destination. To the north of the fork was a rounded, dome-shaped mountain of gneiss, rising some two thousand feet above the river, and we ascended this on the chance that we might be able to see the volcano from its summit.

Leaving our porters in charge of the baggage, we started off at daybreak, carrying only field-glasses and a prismatic compass. We arrived at the summit at 10 a.m., and saw before us to the east and north-east respectively two enormous volcanic cones, the larger one apparently extinct or dormant, and of a dull-grey, almost black colour; the other, emitting a light fleecy cloud of steam, which was drifting slowly northward on the morning breeze, was snow-white, and glittered in the sun as though it were covered with snow.

Everything appeared perfectly tranquil, the only sign of activity being the cloud of steam above the lesser cone. It was evident that we had arrived too late to witness the eruption, which must have been a fine spectacle from this elevated viewpoint. While on the summit we took the opportunity of taking the bearings of the two cones and of several other prominent features. To the north and north-east were rounded hills of gneiss similar to the one on which we stood; beyond these was a magnificent range of mountains with snow-covered summits, amongst which we could detect numerous glaciers.

To the south and south-east lay the long line of jagged peaks of the Palæozoic chain, which we had crossed by way of the valley of the Hutton.

The more northerly of the two streams which flowed to the fork, where we had left the porters, appeared to flow from the foot of the smaller of the two volcanic cones, and this we decided should be our route.

So magnificent was the view from the summit, and so delightful the mountain air, that we were loth to return to the closeness of the valley below, and lingered on, eating a light repast which we had carried in our pockets.

We were sitting facing the volcanoes when suddenly, without the slightest warning, an enormous column of what appeared to be dense black smoke was shot out from the summit of the smaller cone, and rose rapidly to a height which we judged to be about twice that of the cone itself. The column then appeared to open out into an umbrella-like form, and we could see, by means of our glasses, a thick rain of stones falling from its under surface. As the cloud of vapour slowly unfolded itself in the brilliant sunlight, its shining upper surface resembled a gigantic cauliflower. So engrossed were we in watching the development of this beautiful cloud of steam, that we quite forgot the explosion which had caused it, and were startled by the loud bellowing roar which appeared to make the whole atmosphere quiver. As light travels at 186,000 miles per second, we saw the cloud almost at the same moment that it was produced, but the sound, which travels much more slowly (about 1100 feet per second), took an appreciable time to reach us.

As we stood on the summit, several other explosions took place in rapid succession, and as these were even more violent than the first, it was evident that a second eruption had commenced, or that we had arrived on the scene during a temporary lull. We at once made our way back to the fork and started up the smaller stream in order to get as near a view as possible of the volcano.

After a somewhat steep climb by the side of the roaring torrent, we emerged from the valley on to a plateau composed of ancient lava-flows. These had become weathered in the course of ages, and a luxuriant growth of bushes had sprung up, though as yet there were no large trees. We now had an uninterrupted view of the two cones, the smaller one still throwing out clouds of steam at intervals.

After a brief survey of the scene we came to the conclusion that the best place from which to observe the eruption would be some point on the side of the larger, quiescent cone, as it was obviously unsafe to attempt an ascent of the smaller one in its present state of activity. The large cone overtopped the smaller by at least 1000 feet, and we hoped that if we were able to reach its summit we could obtain a bird's-eye view of the whole of the active area. It was much too late in the day to attempt the ascent, so we chose a comfortable corner behind some large blocks of lava at the foot of the cone, and there made our arrangements for the night.

The explosions continued at intervals of about half an hour, and the column of dust and steam was occasionally illuminated by vivid flashes of lightning. After sundown the whole countryside was illuminated by a dull red glow, evidently the light from molten lava in the crater reflected from the steam cloud, which itself glowed red in the intervals between the explosions. Immediately after each explosion the light suddenly increased in intensity and became almost white, though slightly tinted with orange. This light then gradually subsided to the former dull red glow until the moment of the next explosion. At its brightest it was possible to read ordinary print at our bivouac by the light from the crater.

Throughout the night the explosions continued with remarkable regularity, with the exception that occasionally three or four followed each other in rapid succession after a period of repose somewhat longer than the average.

The ascent of the large cone presented little difficulty, but here and there we had to traverse fields of lava which, though weathered to a reddish soil in some places, in others still retained its slaggy, cindery surface, and on these progress was slow, as care was necessary in placing the feet, if we did not wish to have our boots cut to pieces and our feet lacerated.

The condition of the lava-field showed that it was of no very great age, and therefore that this cone also had been active at a comparatively recent date.

Other parts consisted of volcanic ash—as the fine glassy dust blown out of a crater by the explosions is often called—and in these progress was easy, as a certain amount of vegetation had already established itself and to some extent bound the soft ash together.

Nearing the summit, we came upon several open rifts, from which was escaping a small quantity of steam and sulphurous gases, and on reaching the edge of the crater looked down upon an almost circular plain, some 200 feet below the rim and bearing on its surface a group of three small cones, each with a diminutive crater at its summit. From one of these steam was escaping quietly, but was absorbed by the atmosphere before reaching the level on which we stood. In the neighbourhood of several fissures in the crater rim, from which gas was escaping, the temperature of the ground was unpleasantly high, but by walking round to the northern side we were able to station ourselves on a level portion remote from the fissures and free from objectionable sulphur fumes. From this vantage-point we had a magnificent view of the active cone, though, contrary to our expectations, we were unable to see the interior of its crater, as the wall was somewhat higher on our side than on the other.

We had taken up our point of observation about ten minutes when the volcano resumed operations. First there was a distinct quivering of the steam cloud and then followed four explosions in rapid succession, which increased the cloud to something like ten times its former dimensions. The last explosion was the most violent we had yet witnessed, blocks of solid lava large enough to be clearly visible from where we stood being hurled into the air to a height of some 2000 feet. An enormous quantity of solid matter now began to separate out from the cloud and to fall upon the sides of the cone. Many of the larger stones were seen to rebound and then to roll down the mountain-side, while the smaller ones buried themselves in the soft white powdery ash which clothed the surface as with a mantle of snow.

These four explosions appeared to be the forerunners of a more violent stage of the eruption. The whole summit of the cone became shrouded in vapour, and loud bellowings proceeded from the centre of the cloud, while huge globular masses of dust and steam were hurled vertically from its centre in rapid succession. Occasionally stones, larger than the average, were hurled from the cloud, and many of these we saw, by means of the field-glasses, to be either molten or, in any case, very hot, as they left a trail of vapour behind them as they fell through the air. One or two of these bombs fell on the foot of the cone on which we stood.

The weather seemed settled, and there was little reason to fear a change of wind, and we therefore decided to remain on or near the summit for the night, although this was a somewhat risky matter, as in the event of a sudden retreat becoming necessary, it would not be easy to traverse the slaggy surface of the lava-streams in the darkness. However, during the preceding night the light from the cone had been almost continuous, and as any increase in activity would probably be accompanied by a still more vivid glow, we decided to remain.

Half an hour before sundown a terrific series of explosions took place in such rapid succession that it was impossible to count them, and now the cloud of dust and steam appeared to settle down and form a canopy which extended half-way down the cone. This seemed to be due in part at least to a lull in the wind, and as the cloud was spreading in our direction we were preparing for a hasty retreat, when the breeze again sprang up in nearly the same direction as before. The cloud on the lower slopes of the cone now began to thin, and through it we could see a red glow, although there was still a fair amount of daylight. As darkness came on, the glow increased proportionately, but it was as yet impossible to ascertain its cause. Explosions still continued at intervals, but their violence was not now so great. Something appeared to be in progress in the cloud on the far side of the cone, as we could now and then catch a glimpse of its dark outline against a faintly luminous red background of vapour.

While we were endeavouring to ascertain the cause of this phenomenon, there took place an explosion deeper and heavier in character than any we had yet heard. What at first sight appeared to be a sheet of flame was projected from the crater, broke into fiery spray, and fell back in glowing drops into the abyss and on to the sides of the cone. It was evident from this lava-fountain that the molten material had risen high in the crater, and that the red glow on the far side of the mountain probably emanated from a lava-stream. At the same instant a fiery streak appeared on the side of the cone nearest to us, which our glasses showed to be a great crack or rent in the crater wall. From this rushed a fiery torrent of dazzling brilliancy which soon began to spread out laterally as the gentler slopes near the base of the cone were reached, while at the same time its velocity was checked.

The surface of this lava-stream soon began to crust over and to lose its brilliancy, becoming dull red in colour. From time to time rifts would open in this cooler surface and the white-hot liquid below appear as a network of fire. Later the surface appeared to have become solid, but the molten lava was still visible through the cracks. Enormous clouds of steam escaped from the lava along the whole length of the stream, and at several points on its surface miniature volcanoes established themselves, emitting steam and occasionally showers of fiery spray. The lava still continued to pour from the rift near the summit, while the front of the stream advanced now slowly, now with greater rapidity towards the valley between the two cones.

We now got into our sleeping-bags, which had been sent up from last night's bivouac, leaving one man on watch, with instructions to awaken us all immediately in case of any change taking place, but in any event at the first streak of dawn. With the escape of the lava the violence of the eruption seemed to diminish and we were undisturbed during the remaining two hours of darkness.

As soon as the light was strong enough we were again at our look-out station and observed that the lava was still flowing from the rift, though in lesser quantities than at first. The front of the stream had entered and partially filled the valley between the two cones, its surface being everywhere covered by huge masses of slag resembling gigantic clinkers. On the edges of the stream these appeared to be in motion, tumbling one over another in a most curious manner.

After watching the stream for about an hour, we descended the cone in order to approach as near as possible to the flowing lava, which for some time was hidden by a shoulder of the hill. When we again came in sight of it the end of the stream seemed to have stopped, or, at all events, slowed down to such an extent that we could no longer detect its movement from this distance.

While we were watching, the front of the stream suddenly broke down and out rushed a torrent of lava, which flowed at first rapidly, but afterwards more slowly down the valley towards a small lake which lay in the angle between the bases of the two cones. Before reaching the lake, however, this secondary stream, like the first, slowed down and gradually became covered with solid matter. As the lava flowed from the opening in the end of the main stream the surface of the latter slowly collapsed as its liquid support was withdrawn. We now advanced farther, but before reaching the immediate neighbourhood of the stream were obliged to refrain from a nearer approach by the intense heat and the sulphur fumes.

Our supply of water had run short, and as all the streams and springs near the volcano were foul with sulphur and volcanic dust, we had to return to our previous bivouac, where there was a small spring of pure fresh water, to replenish our stock. Here we spent the night and on the following day again visited the lava-stream. We found the front now not more than 30 yards from the water's edge, and were able to approach the moving mass much more closely than would have been possible on the previous day. The surface had become cooler and there was no appearance of molten matter. That there was still liquid within was indicated by the steady onward movement of the great mass of slag and the grinding, tearing noises which constantly came from within.

Climbing a slight eminence, a remnant of an ancient lava-flow, we were able to get a clear view of the front of the stream, where it was advancing towards the lake. The ground in front was covered with grass and reeds, and lumps of slag were continually rolling down from the top of the heap on to the vegetation.

The upper part of the stream seemed to be slowly pushed forward so that the end face became more steep, then masses would detach themselves from the top and roll down, thus restoring the original angle, and this was repeated again and again.

Steam was continually escaping from the crevices between the blocks of slag, and here and there a dull red glow could be seen in some of the deeper cavities. The edge of the swamp surrounding the lake had now been reached, and the fact that the slag, though solid, was still hot, was demonstrated as each fresh mass rolled down into the swamp, when clouds of steam were produced.

As the advancing front sank into the soft ground, the progress of the stream seemed to be temporarily arrested, and the face became steeper and higher than hitherto. So entranced had we been watching the slow, steady, irresistible advance of the stream that it was only now that we realized that this arrest of the movement foreshadowed a catastrophe, and it was well for us that we left the summit of the mound and made our way some distance up the slope of the large cone to a point where we could obtain a clear view from a safer distance.

Hardly had we established ourselves in our new look-out when the whole front of the stream appeared to topple over, and the imprisoned lava rushed out in a torrent and precipitated itself into the lake. We were almost stunned by the sound of the explosions which followed.

What exactly took place we were unable to see, as the whole mass was instantly enshrouded in a cloud of steam, from which showers of stones were shot into the air in all directions. Even here we were not safe, several small masses of spongy lava, still hot, falling round about us, while the mound which we had previously occupied was strewn with blocks estimated at several pounds' weight. The fusilade continued, but after a time became less violent, and the projectiles seemed, for the most part, to be thrown forward across the lake. Nevertheless, after the narrow escape we had had, we did not feel inclined to again approach the stream so closely.

The activity at the summit of the cone, though considerably diminished, was still far too violent to allow of an ascent being made, and as we had still some exploration work to do on the gold-bearing gravels, we returned to Three Forks Camp.

Three weeks later, we again set out for the volcano in the hopes that we should now be able to ascend to the crater. On reaching the rounded hill of gneiss near the junction of the streams, from which we had obtained our first view of the cones, we saw that the eruption had so far subsided as to give hopes of our being able to accomplish the end we had in view.

The volcano was now emitting puffs of steam and occasionally scattering a few stones to windward, but at this distance no sounds could be heard, and the earth-tremors, which were such a constant feature during the height of the eruption, had entirely ceased. We determined to avoid the valley between the two cones, as we knew it to be occupied by recent lava, which, even if sufficiently cooled to allow of a safe foothold, would be very difficult to cross owing to the extreme irregularity and roughness of its surface, and to make our way round the base of the cone to its northern side and attempt the ascent from there.

We first ascended the valley as far as the foot of the lake and then followed the base of the cone. We had to make a considerable detour to avoid a second lava-stream, evidently the one whose light had thrown the cone into silhouette on the night of the climax of the eruption. This obstacle passed, we commenced the ascent. Everywhere the ground was strewn by blocks of solidified lava of irregular form, evidently hurled from the summit crater. These were accompanied by a smaller number of volcanic bombs, some of which were pear-shaped and others had a curious twisted appearance, being masses of lava which had been hurled into the air while in a pasty condition and had solidified before reaching the ground. The cone was deeply covered by loose deposits of volcanic ash, and over the last part of the climb we sank nearly knee-deep in this, at every step raising clouds of suffocating dust.

Arrived at a point 200 feet from the summit, we found it necessary to make a circuit of the cone, in order to avoid the fumes from the crater, and this brought us

Plate XIII.—A Glacier-table.

to the rift whence had issued the flood of lava which we had first seen. Much steam, sulphur dioxide, and hydrochloric acid were still pouring from the rift, but the lava had ceased to flow. On account of the suffocating nature of the fumes, it was impossible to approach sufficiently near to obtain any idea of the depth of the chasm, nor could we ascertain whether it had originally communicated with the crater itself or with the main conduit at a lower level.

At length, after a wearying climb through the soft loose dust, we reached the lip of the crater. Two hundred feet below us was a flat floor, of which we obtained a view at intervals when the vapours were swept aside by the wind. During one clear interval we were able to see that the floor consisted of two parts—a central one, which was constantly heaving, and an outer ring, which appeared more stable.

While we were watching, the central part seemed to swell up into a great bubble, which burst with a roar, hurling fragments of the slaggy crust into the air and exposing the surface of the molten lava below. For some minutes the surface of the lava remained in violent ebullition, fiery jets being projected from its surface to a height of 20 feet or more. It then gradually subsided and became crusted over with a solid scum. This, in its turn, confining the vapours, was once more raised into a dome, to burst in its turn and be followed by another. This was the stage made familiar to us by the writings of Judd[1] and others with regard to the crater on the island of Stromboli, in the Mediterranean,

[1] *Volcanoes, What They Are and What They Teach*, by John W. Judd, F.R.S., 1893, pp. 13 *et seq.*

and which also occurs in certain stages of some eruptions of Vesuvius.

The activity was still too violent and the quantity of vapour too great to allow of a descent into the crater being attempted, though we were able to locate a track, by which, under more favourable circumstances, there would be but little difficulty in reaching the crater floor, and we hoped that, on a subsequent visit, we should be able to accomplish this descent and make an examination of the inner walls of the crater and of the central pit.

CHAPTER XV

CENTRE VALLEY—HOT SPRINGS

Back at Three Forks, we once more attacked the problem of the auriferous gravels. Up to the present we had only explored Centre Valley for a distance of about fifteen miles from the camp. Up to the farthest point we had yet reached the gravels were present, but whether or no they were gold-bearing throughout the entire distance we were as yet unable to say.

We decided to proceed leisurely, as an important find, such as this, required very careful investigation. Wherever the stream had produced natural sections of the gravels we halted and set to work with our pans. Occasionally we drew blank, but usually we obtained indications. No nuggets were found, but there was every reason to believe that the deposits as a whole would pay if worked by hydraulic mining.

Twenty-five miles above Three Forks the valley was about four miles in width and was crossed by great ridges of gravel made up of pebbles of gneiss, schist, and granite, the last of a type we had not previously seen.

These gravels were arranged in several parallel ridges, each bearing mounds upon its surface, and the whole tumultuous mass stretched across the valley in the form of a crescent, having its convex side downstream. In the gravels were numerous scratched stones, such as are found in the glacial deposits of Northern Europe, and it soon became evident that the valley had been formerly occupied by a glacier, of which this was the terminal moraine.

In one or two patches of fine sand which we found in the moraine there were faint traces of gold, but on the whole the gravels were barren.

Above the moraine was an extensive flat, through which the stream meandered, evidently the bed of a former lake, of which the moraine had formed the dam. The lake had been partially filled up by alluvium brought down by the stream and eventually drained by the cutting down of the channel through the obstruction.

The alluvium appeared to be rather more promising than the moraine gravels, but in this flat part of the valley sections were small and few, and in consequence we passed on to explore further. Beyond the lacustrine deposits were gravels similar to those found in the moraine, and again they appeared to be barren.

This part of the valley was very unlike the portion below the moraine. In the lower part the usual cross-section was V-shaped, whereas here it was distinctly U-shaped, the sides being precipitous and the small tributary streams tumbling in over steep and lofty waterfalls.

About thirty miles from the camp we came upon a magnificent waterfall almost equal in volume to the main stream above the junction. This stream came in from the north, and at the foot of the fall was spread out a great fan of gravel containing large numbers of the small white pebbles of quartz which we had found associated with the nuggets near the camp, a fact which determined us first to explore this stream and then pursue our researches in the main valley, should time permit.

The stream below the fall was cutting through gravels, and nowhere could we find solid rock, the surface of which was evidently below the level of the stream bed. Under these circumstances it was, of course, impossible for us to sink a shaft or pit down to the rock surface, as such an excavation would at once fill with water, we being unprovided with any pumping apparatus.

This was unfortunate, in view of the fact that it was at the base of the gravels in contact with the solid rock that we had found most of the gold in the other sections.

The climb up the cliff-like side of the valley was a stiff one, and it was with considerable difficulty that we were able to transport even our light equipment to the top. Arrived at the summit we saw stretching out before us a broad V-shaped valley, very unlike the one we had just left. For some distance from the head of the fall there was nothing but bare surfaces of gneiss, the stream rushing with great violence down a narrow gorge towards its plunge into the valley below.

Following the edge of the gorge, we at length entered the normal valley, and here there appeared to be much the same arrangement of the alluvial deposits as in the valley below the moraine.

This was a hanging valley, and the great U-shaped trench in which the main stream flowed appeared to have been eroded by the glacier, as at several points on the cliff face we had observed striations, such as are produced by glacier-ice alone, amongst the agents of denudation.

The gorge at the head of the fall doubtless represented the amount of cutting effected by Gold Creek—as we afterwards named this stream—since the retreat of the ice from this part of the main valley, and the fall was the result of the rapid ice-denudation upon the main valley, from which that of the tributary had been free.

Before the glacial episode the gravels of the hanging valley had probably been continuous with those of the main valley below the moraine, and this theory gave us renewed hope of again striking the gold-bearing beds and possibly also of discovering the source of the quartz pebbles, and hence, in all probability, that of the gold itself.

The gravels lay in great flats on both sides of the stream, the course of which was winding. Here and there were sills of rock in the stream track which indicated that the rocky floor of the valley was at no great depth, though for the most part gravel-covered.

On the flanks of the valley were several terraces of alluvial materials, the relics of ancient flood-plains, formed at a time when the valley had not been cut so deeply as now.

As the bottom of these terrace gravels would, in all probability, be above the water-level, we selected a site for a trial shaft near the foot of one of the higher terraces, the gravels of which had yielded a fair "colour" in the pan.

The process of excavation was tedious, as we had to make a large open pit with sloping sides, there being no trees in this upland valley from which to cut timbers for lining purposes. Constant care had to be exercised lest the sides of the trench should collapse and bury the worker, but it was a fortunate circumstance that at the point we had selected the gravels were only 16 feet thick. From top to bottom these gravels yielded well, and the lowest bed was again richer than those above. The actual yield of gold was small, owing to our being unable to treat most of the "dirt" excavated, but one small nugget served to show that we were still on the track.

This excavation took some time, as we had only two shovels in our outfit and only a small prospector's pick, and now as the season was far advanced we had to consider the question of getting down the river before the floods of late autumn made navigation dangerous. The temptation to complete the exploration of this valley was, however, too great for us, and we determined to spend another week upon it. Our provisions were running low, but we were able to shoot a number of grouse, which were very good eating, while an occasional wild sheep also replenished our larder.

At the mouth of a tributary stream we made the richest discovery of gold that had as yet fallen to our lot. This stream had recently, from some cause or other which at the time we were unable to investigate, changed its course, and had cut a channel through the upper gravel terraces.

The materials thus excavated had for the most part been carried into the main stream and washed away, but some of it remained in pockets in the bed of the tributary and as spreads of gravel in its immediate neighbourhood. This action had resulted in a concentration of the gold of the terrace gravels, only the lighter materials having been carried away.

Nuggets, though small, were of quite common occurrence, and we were able to collect and carry away twelve and a half pounds weight. The deposit from this stream was of course of very small extent, but it showed the enormous possibilities of the terrace gravels, and their suitability for hydraulic mining.

We now gave orders to prepare for the return to civilization, and while our impedimenta were being got down the cliff to the main valley, we made a final dash upstream, and were fortunate in finding two large quartz veins cutting across the valley in an east and west direction.

In one of these we were able to detect iron pyrites and also tiny specks of gold, but in the other pyrites only in the portion exposed. In a gold-bearing district, however, the presence of iron pyrites is usually considered a favourable indication.

One final observation we made, namely, that the river gravels above the outcrops of these quartz veins still contained quartz pebbles, a certain indication that there were yet other veins farther upstream, and that, therefore, the possibilities of this wonderfully rich district were not even yet exhausted.

We were able after a rather exciting climb to reach the bottom of the cliff just as the light failed, and we had to make a halt as travelling over this broken ground was impossible in the darkness. It was, however, about full moon, and we hoped to be able to make a start a few hours later, so as to reach a point within a day's march of Three Forks before turning in.

In this we were disappointed as the sky became heavily overcast and there seemed little probability of there being sufficient light by which to travel.

We therefore made the best bivouac we could, and settled for the night. About midnight there came on a cold, drizzling rain which increased in violence towards the morning, with the result that we were drenched to the skin through our sleeping-bags. We had stayed just a day too long, and the rains had evidently commenced.

Chilled to the marrow, we were only too glad to make a start the moment the light was sufficiently strong, not even stopping to make coffee, as our fire had been extinguished by the downpour and there seemed little chance of our being able to light another in the drenched condition of the brushwood. So we made a move and ate some grouse which were left from last night's supper, as we walked. We hoped by this early start to be able to cover the 30 intervening miles and reach Three Forks before nightfall.

All day long the rain fell in torrents, and we trudged along in our wet clothes, with the added weight of the water in our sleeping-bags and the gold and other samples which we had collected. Towards sundown the weather moderated somewhat, and when darkness came upon us some 7 miles from camp, the sky had cleared, and after a three hours' wait, during which we had to keep moving about in spite of our fatigue in order to keep ourselves warm, we were able to resume our tramp by moonlight, and eventually reached camp a little before midnight.

Here we found the canoes had been overhauled and everything got ready for an early departure. Having changed our clothing and partaken of a hot supper, we retired to our tents for the night.

The following day we found the river greatly swollen and quite unsafe for our small craft, but we were somewhat reassured by a bright sunny day, and by the fact that only the Centre Valley Stream was in flood, those in East and West Valleys being normal. This fact showed us that the rain had been local, and that in all probability the stream would subside as rapidly as it had risen.

Before we retired that night, the waters had already fallen several inches, and everything was got ready for a start in the morning. The tent was struck and stowed away in the canoes, only the sleeping-bags and cooking utensils being left for the morrow. The journey to the base camp was uneventful, and the launches were found to be in good order; but as several days would be required to stow away the canoes and make up the supply of wood-fuel, and as the weather remained fine, we decided to make a short expedition along the foot of the Silurian hills to the east of the river.

We followed the banks of a stream which was too small and rapid to be navigable, and found that the Silurian rocks extended for a long distance in an easterly direction, several fossiliferous exposures being encountered. On the second evening we found ourselves at the junction of a tributary stream which flowed in from the north, and were unable to proceed farther as this had to be crossed, and a heavy fog filled the valley, making the opposite bank invisible. We had had little rest for the past ten days, and consequently did not awaken until the sun was well above the horizon and the mists were beginning to disperse.

We had slept close to the bank of the tributary stream, and although it was still misty there was a curious warmth in the air quite unlike anything we had previously experienced on a misty morning. Having lighted a fire and made the preliminary arrangements for the preparation of breakfast, we went down to the stream for a morning dip. On entering the water we were surprised to find that it was quite warm, a thermometer plunged in it showing a temperature of 65° Fahr., although that of the air was below 40°.

This difference in temperature between the water and the air was quite sufficient to account for the curious steamy fog which still overhung the water, and we decided while eating our breakfast to ascend the tributary with a view to ascertaining the cause of its abnormal temperature. As we advanced along the valley we found that the temperature of the water increased, and it soon became evident that the stream carried the overflow of some hot spring, as no other explanation seemed possible. Eventually we found ourselves in a sort of basin surrounded on all sides, except that by which we had entered, by steep slopes. Towards the centre of the valley hung clouds of steam. On entering the hollow we found its floor covered with a curious incrustation of silica, in places pink, in others white, but always with a beautiful opalescent appearance. The waters of the stream gave off a considerable amount of steam, and were so warm that we could with difficulty keep our hands in them. There now appeared numerous springs from which water little, if at all, below the boiling point welled out continuously, and from some of these occasional spouts of water were thrown several inches into the air by escaping steam jets. Near the centre of the basin was a raised mound of travertine, as the deposit of silica is called, and in its centre was a crater-like hollow 10 feet in diameter, in which the water was boiling freely some 3 feet below the lip. While we were watching this we noticed that the level of the water was rising, and as, in all probability, it would soon overflow, we made a hasty retreat from the mound and struck out for higher ground.

We had gone only about a hundred yards, when we heard behind us a gurgling sound, and, on looking back, saw the water was being expelled from the crater in a series of gushes accompanied by much steam, and then without further warning a column of water and steam shot up to a height which we estimated at 100 feet. This boiling fountain continued to play for several minutes, and then suddenly subsided after a final burst of steam. We had been fortunate in making our hasty retreat to windward, as had we been on the other side of the vent we should, in all probability, have been badly scalded by the boiling spray.

The Dome Geyser, as we christened this spring, was now shrouded in steam which was rising in clouds from the hot water in the surrounding pools and rivulets, but when this subsided, as it did in the course of half an hour, we again ventured to approach the crater. There was now no water visible in the funnel, and we could see to a depth of about 15 feet, beyond which the view was obstructed by vapour. On walking farther up the valley we found numerous hot springs and several other geysers.

One of the latter had a travertine cone shaped like a beehive, and in the case of another the water issued from the summit of a travertine tube 12 feet high and 4 feet in diameter.

At the foot of the steep slope which formed the head of the valley we came upon a beautiful series of travertine terraces in some respects not unlike the stalagmite basins which we had previously seen in the caves of the limestone plateau near Lyell. On ascending these pink, white, and pale-green marble-like steps we found on the top of each a pool of clear water slowly overflowing the lip and fed in its turn by the overflow from the pool on the surface of the terrace above. The source of the water, which as it flowed from basin to basin gradually cooled and deposited its dissolved silica, was a hot spring near the foot of the rock wall.

The temperature of the water where it issued from the spring was 150° Fahr., but in the pools on one of the terraces we were able to have a hot bath, a luxury we had been unable to obtain since we left Lyell in the early spring.

On the way up the valley we had shot several wild fowl of the pheasant tribe, and these we were able to boil in one of the springs by tying them up, together with a large stone, in a canvas bag, and lowering them by means of a cord into the boiling water.

The most interesting phenomena in this valley, which we judged from the distance and the direction in which we had travelled to be in the same belt of country as the active volcano which we had previously visited, were the great geysers. These are probably the result of deep tubes penetrating from the surface to some heated mass of rock below. The water at the bottom of this tube becomes heated by contact with the hot rock, and would, under ordinary conditions, circulate by convection until the whole mass reached the boiling point, when ebullition would take place and steam be disengaged at the surface, the point of least pressure.

Owing chiefly to irregularities in the tube, and partly also, in all probability, to the presence of dissolved silica, the distribution of heat by convection is prevented, or, at all events, seriously hindered, with the result that the water under pressure at the bottom becomes heated up to the boiling point. At first this will be kept in the liquid form by the pressure of the overlying column of water, until at length, as the temperature rises still higher, a small quantity of steam is generated, which by its expansion causes the water to rise in the crater, as we had seen it do before the eruption from which we so narrowly escaped.

As soon as the water commences to overflow, the pressure on the heated portion of the column below is relieved, and, as its temperature is probably several degrees above the boiling point at normal atmospheric pressure, the water in this lower portion of the pipe at once flashes into steam and drives out the column of cooler water above it with much violence.

The pipe then slowly fills up again either from below or from above, and the process is repeated.

In one of the more active of the boiling springs we were able to produce an eruption of the geyser type by throwing in several large stones which probably became jammed in some narrow part of the conduit and provided the necessary check to convection. About ten minutes later the spring erupted with great violence and the stones were flung out along with the water. There were no signs of geyser action having taken place at this particular spring under normal conditions.

We now returned to the base camp, and on the day following our arrival set out downstream *en route* for Lyell. The journey was uneventful, with the exception that we had some difficulty in passing through the rapids in the deep valley between the Lake Fault and the Camp Fault.

Arrived opposite the great lead vein, we were surprised to notice several wooden huts on the bank of the river, and, thinking that work had been started on the vein, we attempted to land, but were informed by police officers that this land was now Government property and that no person was allowed to land without a permit. Evidently this was some political dodge on the part of the Government, so we merely accepted the decision of the officer and, without disclosing our identity, continued our journey towards Lyell.

Arrived at a point about 5 miles above the junction of East River with the Hutton, we were met by the Premier's launch, which was cruising about with orders to intercept us and to deliver certain sealed orders. These we found to be instructions to transfer ourselves and our belongings to the private launch and then to send the two Government boats back with all hands to the police camp at the lead vein.

Accordingly we reached our own steamer in the Premier's launch after what we considered some unnecessary delay shortly after midnight. We were requested in our sealed orders to remain on board and not to hold any communication with the shore, until we should receive a communication from headquarters. Thus our return was known only to the crew of the private launch and to our own men on the steamer. We had not long to wait for an explanation of our curious treatment, as early the next morning a boat came alongside and the Premier himself climbed on to our deck.

He explained that during our absence the outcry against the so-called extravagance of the Government had increased tenfold, and that the expenditure upon our survey was considered their crowning folly. He was in consequence extremely anxious to learn if our expedition had been a success, as in that event it might still be possible to win at the elections.

After obtaining the knowledge of the big lead-silver vein he had quietly pushed through the legislature a bill vesting all mineral rights in the nation, and as this bill was thought to refer merely to the coal which we had found near the Hermitage and at B.H. 2, in which many of the members had small faith, there had been little or no opposition. He had thought of announcing the discovery of the lead vein shortly after the passing of the minerals bill, but decided to hold it over as an election surprise.

"And now, gentlemen," said he, "what account can you give of yourselves? I hope you will be able to say that other lead veins occur in the far north."

We were obliged to confess that we had not up to the present discovered any other veins similar to that between the great faults, and, seeing the Premier's anxious face, we produced a strong canvas bag from a locker, untied the string, and rolled the contents of nuggets on to the table.

When telling him of the extensive nature of the deposits from which the gold had been obtained and the enormous wealth which they contained, we congratulated him on the foresight which he had shown in passing the minerals bill, and thus securing for the country a most valuable asset in the form of royalties or such other charge as might be determined upon.

We then further told him of our hopes of oil being found in paying quantities in the Jurassic country between the two ranges of mountains.

The elections were to take place in a week's time, and on the evening following our arrival the Premier was giving a dinner to the members of the Government, and to this we were invited in order that we might give an account of our discoveries. Some of the members were inclined to be sceptical, but the production of some of the larger nuggets, which were passed from hand to hand, soon removed all doubts. The following morning the Government organs in Lyell, Red River, Smithford, and Port Hutton contained glowing accounts of the work of the Survey, and many sarcastic remarks about the charges of wasting public funds which had been so freely indulged in by the opposition, and further, pointed out the enormous advantage which would accrue to the State owing to the passing of the minerals bill.

It was even suggested that the National Debt, which, though not large, was nevertheless a considerable burden on so small a community, could in the course of a few years be completely repaid.

The elections duly took place, the Progressive party was returned with a larger majority than ever, and we had now to look forward to a busy winter devising means of starting work on the goldfields and arranging for our expedition in the following spring.

CHAPTER XVI

FURTHER EXPLORATION OF CENTRE VALLEY— GLACIER ACTION

In the spring of our third year in Geologica we set out from Lyell somewhat earlier than in the previous year, as we wished to make a thorough investigation of the country at the head of Centre Valley, and, as it would be necessary to establish a considerable dépôt at Three Forks, an early start seemed desirable.

There was still a large quantity of flood water coming down the Hutton, but already most of the principal shoals had been surveyed and buoyed as far north as the Lake Fault, and this considerably reduced the risk of navigation.

Work had now been commenced on the large lead vein between the faults, and a small village of wooden huts had already sprung up. We landed to inspect the work, but as yet little had been done except in the removal of the cover of loose earth from a part of the vein, and the commencement of a rope railway to bring the ore to the foot of the cliff, where it was intended to erect a smelt mill and a refinery.

We were accompanied on this occasion by a small tug-boat carrying a party of engineers and towing a couple of barges which contained a boring plant for the exploration of the oil-field. We were instructed to land with this party and to give instructions as to the exact sites which we recommended for the trial wells. This being accomplished, we were able to go on to Three Forks without further delay, and eventually reached our old camping-ground without any untoward incident having occurred.

We were to be followed in a week or so by a surveying party, who had been instructed to make an accurate survey of the gold-bearing region and to plan out a town at Three Forks. They were to be followed by a strong draft of military police, as it was expected that in all probability there would soon be a large population on the spot.

Having started the dépôt, we had some days to spare before we could take up our work in Centre Valley, for, although the winter was over, there was still much snow in this elevated region, and the upper part of the valley would not be sufficiently clear for our purpose for some few days, although rapid melting was even then in progress.

West Valley appeared to contain less snow than either of the others, and we, therefore, took the opportunity of making a further inspection of the volcano. The lava-stream which we had seen flow into the lake on our former visit had now become solid throughout, though its interior was still at a high temperature.

Solid lava is not a good conductor of heat, and we were able to traverse the stream without inconvenience except from the fumes which issued from some of the fissures. This saved us the long detour which we had previously had to make. There was little, if any, vapour visible above the crater from the foot of the cone, but on climbing to the summit we saw that a small cone inside the main crater was still feebly active, emitting from time to time puffs of steam, with a few small stones and a little dust, these having built up a cone of considerable dimensions. We were able on this occasion to climb down the interior of the large crater and to explore its floor. When viewed at close quarters the small central cone was seen to consist of two cones, the one within the other, and all composed of "ash."

It was evident that at the height of the eruption the whole of the large crater had been active, but at a later stage the explosions were not sufficiently strong to propel the loose materials beyond its walls, with the result that a small cone was built up within the large one, and, with a still further diminution of activity, a third and still smaller one within the second.

FIG. 31.—Successive stages in the development of a volcanic cone.

Should the activity continue in its present mild form the innermost cone would soon overtop and obliterate the second, and eventually the whole of the large crater would become filled up and the volcano once more consist of a single cone (Fig. 31).

Having returned to the surface of the lava-stream, we found numerous small cones scattered over it. These did not appear to be connected in any way with the main volcanic focus, but to have been caused by the escape of steam from the lava.

We now ascended to the summit of the larger cone, and succeeded in this case also in reaching the bottom of the crater. We noted that in several parts of this crater, and also in some fissures on the west side of the cone, there were deposits of sulphur of sufficient importance to serve as a source supply of that commodity.

Having returned to our old camping-ground at Three Forks, we set about the arrangement of our stores and the fitting out of packs of provisions for a more extended journey into the mountains than any of the previous ones. Before leaving on the main expedition we pegged out certain areas of the gold-bearing gravels, as being most likely to yield richly, so that the men of the expedition following us might have some guide as to where to make a start. We also surveyed the site for a dam to provide the necessary water pressure for the hydraulic mining.

This being accomplished, we made our way up the valley to the great moraine near the mouth of Gold Creek, and thence proceeded up the main valley. Everywhere were to be seen signs of the former presence of the glacier.

Ice-scratched blocks were strewn around on every hand, while mounds and ridges of gravel encumbered the wide floor of the valley. Here and there, where the solid rock peeped through the covering of glacial débris, its surface was polished and striated, and so fresh were these markings that it was obvious the glaciation must have taken place at no distant date.

Some of the gravels consisted of rounded pebbles, were highly current-bedded, and were obviously the

Plate XIV.—The Great Ice-fall.

product of running water. Others again were arranged in mounds of irregular form and were more angular in character, suggesting moraines similar to the one near the mouth of Gold Creek. They were, however, smaller both as regards the height of the mounds and the breadth of country which they covered.

All these deposits appeared to have been formed during the retreat of the ice towards the head of the valley, the moraines marking the halting-places at which the ice-front had stood for some time, and the intervening spreads of water-worn gravel, the spaces over which the retreat had been rapid.

Here and there rounded bosses of rock protruded from the gravels, and these were found, upon examination, to be much more rounded on their upstream sides than on the downstream, which were often broken and craggy, the sides being smooth and striated. These were typical *roches moutonnées*, such as abound in all recently glaciated countries. So marked was the degree of rounding on the upstream ends of these bosses in one section of the valley, that the type of scenery was quite different, according as one happened to be looking upstream or down. Looking up the valley only the rough craggy ends of the *roches moutonnées* could be seen, and the scenery was, in consequence, wild and irregular, while, on turning oneself about, the rounded flowing outlines of the smooth surfaces took the place of the rough crags.

In the bare smooth surfaces of the *roches moutonnées*—which consisted chiefly of gneiss—we were able to trace numerous dykes of basalt and also of another type of igneous rock known as quartz-porphyry. This latter is closely related to granite, but having been cooled more rapidly than that rock, is somewhat finer in grain and frequently contains some glass by way of ground-mass, in which crystals of quartz, felspar, and a little mica are embedded.

The crystals of felspar in these dykes were, in some instances, upwards of an inch in length and were very perfectly formed, showing that they must have been produced under conditions of slow cooling, probably in a great granite reservoir, while the fine-grained ground-mass indicated much more rapid cooling, such as may have been caused by the injection of the molten matter, with its floating crystals, into the crack or fissure where it eventually solidified to form the dyke.

In a small tributary which entered Centre Valley from the north we found in some gravels several crystals of tourmaline and some small pebbles of tin-stone, together with numerous rounded masses of granite similar to that previously encountered here and there in the lower part of Centre Valley. We made a note to explore Tin Creek, as we named this stream, on our return journey, should time permit.

We now reached the foot of a moraine much higher and more massive than any which we had as yet encountered, and on reaching its summit found a large lake occupying nearly the whole width of the valley on its upper side. The outlet of the lake was not in the centre of the valley but on its western side, and on visiting it we found that the stream occupied a deep gorge in the solid gneiss.

When the ice had retreated from the moraine the lowest part of this had evidently been at the western side of the valley, and by this lowest part the waters impounded between the ice-front and the ridge of morainic débris had overflowed, and after cutting through the thin layer of loose material had continued the excavation of its channel in the solid rock below on the same line. In the lake were several rows of small islands, evidently the highest parts of smaller moraines now almost submerged beneath the waters.

At the upper end of the lake was an extensive delta, formed by the waters of the inflowing river, which had extended for nearly two miles from the original mouth of the stream. Little material was now being added to the delta, as the waters of the stream appeared clear and free from sediment. Round the shores of the lake was a deposit of gravel, resembling to some extent a shingle beach, but consisting of smaller pebbles. This was several feet above the present water-level, a fact that was doubtless due partly to the higher level of the water during winter and early spring, when the floods come down from the melting snows on the higher ground.

Above the upper end of the lake we encountered another dyke of quartz-porphyry, with large pink felspars, similar to the one near the mouth of Tin Creek, and immediately above this a small tributary stream flowed in from the north, and as the gravel in its bed consisted of large and angular pieces of granite, we concluded that the main mass of that rock was not very far away.

We stuck to the main stream and pushed forward as quickly as our impedimenta would allow. Of this we had a considerable amount, as, in addition to camp outfit, we had also a supply of ice-axes and ropes, which would be required when we reached the glaciers, of which we could now get occasional glimpses.

Owing to the roughness of the ground we were unable to travel more than fifteen miles per day, and on some days this was reduced to seven or eight, when we had to traverse moraine-covered country.

There was little of interest in the next section of the valley, though we were able to locate two further quartz-porphyry dykes of considerable size, both of which contained a few small crystals of tin-stone and tourmaline, but not in sufficient quantities to pay for working.

When within about two days' march of the foot of the glacier, we noticed, on an outlying spur of the hills on the north-east side of the valley, three curious cuttings, one above the other. They seemed to connect the near side of the spur with the valley of a tributary stream which lay beyond it, and had a strangely artificial appearance. On climbing up to these we found that they were large trenches with precipitous sides and flat floors. They were obviously the work of running water, but were entirely streamless, though each had a great spread of gravel covering the hillside at its lower end. Under existing conditions there was no possible catchment for a stream in such a position, and hence we concluded that they were the overflow channels of a lake which had occupied the valley of the tributary at a time when its mouth was closed by the ice of the glacier in the main valley.

We made careful measurements, by means of our aneroid barometer, of the relative levels of the upper, or intake, ends of the three channels, and found that they were 830 feet, 745 feet, and 690 feet respectively, above the level of a point on the stream in the main valley. The ice, closing the mouth of the tributary valley, had originally stood across the spur at the 830 foot level. The impounded waters had evidently overflowed between the slope of the spur and the side of the glacier, and gradually cut a notch which continued to take the surplus waters until the ice-level had fallen below the level of its intake. It had thus opened a lower outlet which eventually gave rise to the second notch, while a repetition of the same process produced the third and lowest. Streamless valleys of this type we knew to be quite common in the glaciated portions of the British Isles, and we hoped that we might possibly see them in process of formation amongst the glaciers at the head of the valley.

An investigation of the spur, through which the channels had been cut, showed that it was due to the presence of one of the large dykes of quartz-porphyry, such as we had seen in the valley of the main stream.

Just above the mouth of the tributary was another moraine, much fresher in appearance than those lower down the valley, and on its northern side was a small lake which had once been much larger, but had been partially filled up by the delta of the stream which issued from a gorge at the foot of the glacier.

The waters of this stream were milk-white with rock-flour ground from the solid floor and sides of the valley by the friction of the stone-charged ice of the glacier, and bearing eloquent testimony to the enormous erosive power of moving ice. Thousands of tons of this rock-flour must be brought down annually by the waters of this stream alone. The presence of this small lake, which was acting as a settling-tank for the solid matter in the stream water, accounted for the clearness of the stream where it entered the larger lake below, and for the fact that the delta there was no longer in active growth.

We now reached the foot of the glacier itself, and established a camp not far from the ice-front, so that we might be able to observe the various phenomena in progress at our leisure. All hands were thankful for the prospect of a rest after the forced marches of the last few days, and consequently an investigation of the end of the glacier, which was within a quarter of a mile of the camp, was made the next item in our programme.

The stream which issued from the end of the glacier was running in a deep, narrow gorge, the walls of which were in many cases overhanging, and as the water occupied its floor from side to side we were unable to effect an entrance.

The rocks were everywhere fluted and striated by the action of the glacier, and most of them bore the characteristic form of the *roche moutonnée.* The loose stones which were scattered over their surfaces also showed unmistakable signs of the rough treatment which they had received, many of them being striated. There was, however, a large number of angular stones which borne no signs of glaciation, nor yet of water action, and these we afterwards found to be derived from the stony materials borne on the top of the ice, and which, in consequence, had been subjected to ordinary atmospheric weathering only.

At the upper end of the gorge a tongue of ice penetrated it for some distance from the surface, and it was from beneath the curtain-like termination of this that the water rushed as a foaming torrent.

Part of the ice-front, that in the centre of the glacier, terminated in a thin edge, beyond which the surface rose in a very gradual slope, being strewn with angular stones and furrowed by very numerous stream courses, cut deeply into the ice, and receiving the waters produced by the melting of the glacier in the bright sunshine.

The glacier at its termination did not cover more than half the width of the valley, there being wide tracts on either side covered with angular gravel disposed in long, steep-sided ridges parallel to the valley sides. These were lateral moraines, and one of them could be seen in course of formation. The angular stones and sand from the surface of the glacier could be seen sliding down its sloping side and accumulating as a talus at the foot of the slope, and it was not difficult to see that the result of a further recession of the ice would leave this talus in a sharp-topped ridge similar to those which flanked the ice for considerable distances on both sides of the valley.

At intervals between this area of lateral moraines and the gorge the ice-front was nearly vertical, and here the glacier could be seen to consist of definite layers, giving the whole a banded structure. At one point a small stream emerged from an archway under the glacier, and the beautiful pale-blue colour of the ice could be plainly seen, the interior of the ice-cave being like some beautiful fairy grotto. Here the character of the stones and boulders was in marked contrast to that of those in the lateral moraines, they being for the most part striated, while, as already seen, those from the surface of the ice were rough and angular.

In many places where clear sections of the glacier were to be seen, it was found to consist of alternate layers of dirty and dirt-free ice, and in one instance there appeared to be a perfect transition from frozen gravel at the base to clear ice above. So perfect was the transition that it was difficult to point to any particular level and say where the ice ended and the ground moraine, as this bottom deposit is called, began.

On one of the large rounded bosses of rock near our camp were well-marked striations running in more than one direction, and occasionally crossing each other almost at right angles. This intercrossing of striæ was doubtless due to the ice moulding itself round the more prominent masses, gradually reducing them in size, the direction of movement at any given point being determined by the form of the rock.

That the ice was in movement could only be detected from the dull, tearing sounds which occasionally were to be heard proceeding from the interior of the glacier, and by the fact that although the ice was melting rapidly, the ice-front remained in the same position for days and even weeks, showing that the supply must have been kept up by a forward movement from behind.

We were able to ascend the face of the glacier with little trouble, as the sand and stones with which the surface was covered offered a fairly good foothold, but where the bare ice was encountered we found it necessary to cut steps by means of our ice-axes.

There were numerous deep rifts or crevasses in the ice, and near the termination these were arranged roughly parallel to the sides of the valley, but slightly inclined outwards like the ribs of a fan. As we left the termination behind, these longitudinal crevasses became fewer and fewer, until when we arrived on the top of the slope they had entirely disappeared.

We had now before us a wide spread of rough ice with many scattered blocks of gneiss and granite and numerous long ridges of stones and rubbish upon its surfaces. Away in the distance the ridges of rubbish—"rock-trains" as they are often called—appeared to coalesce, so that, in place of the twenty or thirty which were present near the termination, there were but four, but these were much larger.

The small rock-trains appeared to have been formed by the subdivision of the larger ones, and we determined to find out if this were the case, and, if so, how it came about; we therefore walked some distance towards the head of the glacier.

Some of the larger rock-trains stood 30 feet above the general surface, and appeared, at first sight, to consist entirely of stones and sand. Careful examination of one of them revealed the fact that it consisted for the most part of a ridge of ice with a comparatively thin coating of rock débris on its surface.

The effect of sand and stones upon the rate of melting of the surface depends upon the size of the stones and the thickness of the layer. Let us first consider the case of detached stones. The direct rays of the sun have little melting effect upon the ice, as the greater part of the heat is reflected from its surface. Stones, however, absorb the heat, and soon themselves become heated, and the same is true of the sand and fine gravel. Now, if the stone or layer of sand be too thick to get warmed through in the course of a day, it will have a protecting influence on the ice beneath, but in the case of small stones or thin layers of sand the effect is otherwise, as the rocky materials absorb the solar rays and transmit the heat to the ice below, which is thus melted.

Individual pebbles may often be seen at the bottom of round holes little bigger than the diameter of the pebble. A thin layer of sand also seems to have a similar effect, a thin deposit of this material being found at the bottom of all the shallow pools which abound on the surface.

Large stones, too thick to get hot through in the day, act as a sunshade and protect the ice beneath them from the heat rays, and thus after a time, as the surrounding unprotected ice slowly melts, they are left standing on a short pillar of ice, forming what are known as glacier-tables (Plate XIII.).

The thick layers of sand and stones forming the rock-trains have a similar effect, and thus the ice beneath them remains as a ridge, as the general surface is lowered. These ridges become higher and steeper as time goes on, until at length the débris slides down their sides, forming two parallel ridges. The central ridge, now deprived of its protective covering, soon wastes away, while the lateral ridges afterwards go through a similar evolution, and thus one original rock-train may become split into a large number, and, in fact, in some instances the débris becomes finally almost evenly distributed over the whole surface, near the termination.

The rock-trains evidently originated in the upper part of the glacier, and we had, therefore, to postpone a study of their mode of formation until we should be able to penetrate farther in the direction of the great snowfields which fed the glacier.

Several tributary valleys joined the main one on both flanks of the glacier. Two which we visited on the east side discharged their waters into the area occupied by the lateral moraines, forming a small lake whose waters eventually escaped through the narrow gaps between the moraine-ridges.

A third valley higher up on the same bank we found to contain a lake, the waters of which were held up by the ice of the glacier, which here occupied the main valley from side to side. The overflow of this lake escaped by a short channel cut through the solid rock of the spur, and was eventually discharged into the moraine tract. This action was precisely similar to what we believed to have taken place in the case of the dry channels described on p. 260.

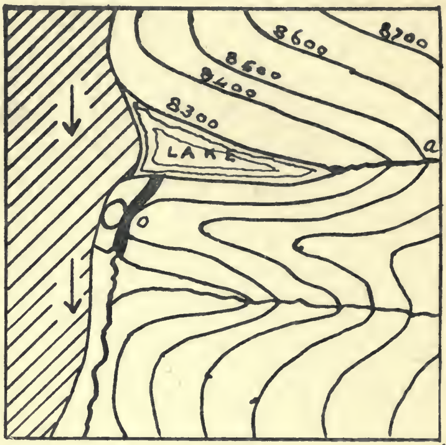

FIG. 32.—Map of glacier lake. *a*, Overflow channel.

The edge of the ice curved into the lake in the manner indicated in Fig. 32, and the surface of the water was dotted over with small icebergs which had broken away from it.

Such lakes are well known in many parts of the world where glaciers exist, for example, the Merjelen See on the flank of the Great Aletsch Glacier, in which case, however, the col at the head of the valley "*a*" in Fig. 32—being lower than the surface of the glacier —takes the overflow, and the channel is cut in that position instead of being through the spur.

The position and level of many such lakes, which formerly existed in the British Isles, can be determined by those of their overflow channels which still persist as streamless valleys in a position where the existence of a stream would be impossible under existing conditions.

On ascending the glacier still farther we found that the tributary valleys were occupied by glaciers which had shrunk away from the main stream and were no longer confluent with it, though one, the uppermost of its class, still contributed ice to the main flow through the medium of avalanches. This glacier terminated at the top of a precipice on the side of a mountain, and as it was slowly pushed over the edge by the weight of the snow behind, mass after mass broke away and came thundering down upon the surface of the main glacier. Naturally we had to give this place a wide berth, but we were able to see by means of field-glasses that much rock débris came down with the ice and contributed in no small degree to the rock-train material.

When we came to examine the first tributary that was actually confluent with the main stream, we found that it possessed two rock-trains, one on either side, and that these consisted of material which fell upon its surface partly as avalanches and partly as stone-showers from overhanging cliffs of rock.

These stone showers, we found, took place chiefly in the early evening and soon after sunrise. They are well known in most mountain districts as morning and evening stone-showers, and are produced in the following manner. During the day the rocks in these high altitudes (we were now, we estimated, some 8000 feet above sea-level) become strongly heated by the direct rays of the sun, though the clear air, free from dust and containing but little water-vapour or carbonic acid, the great absorbers of radiant heat, remains intensely cold. Thus as soon as the direct rays of the sun are removed from the surface of the rock by the setting of the orb of day, or by the shadow of some mountain peak, it is in the condition of a hot body suddenly plunged in a cold medium. The result is, that its surface layers lose heat rapidly and consequently contract, and as the conductivity of rocks is low, the interior remains hot, with the result that the rapid contraction of the outer chilled layer causes a fracture and the dislodgment of fragments which, falling down the mountain-side and dislodging other loose pieces of rock in their track, form the evening stone-showers.

The rock-train on the downstream side of the tributary carried by the movement of the ice round the angle separating the valley of the tributary from that of the main glacier, became eventually the lateral rock-train of the latter, while that on the upstream side, after amalgamating with a similar train on the main stream, was carried on down the valley separated from the ice-edge by the ice of the tributary, forming one of the numerous medial rock-trains which we had noticed in such profusion near the termination of the ice above our camp.

At first sight it might appear possible to determine the number of confluent tributaries by that of the medial rock-trains on the surface of the main stream, and this indeed would be so, were it not for the splitting of rock-trains, which we have already observed, and for the fact that a medial train may sometimes arise in quite another manner in the middle of a glacier. Such a case we were able to examine some miles farther up the glacier, and not far below the point where it left the great snow-field which gave it birth.

Before reaching this point, however, we had to cross a great stretch of broken ice, with numerous deep crevasses and thousands of fantastic pinnacles or *seracs.* This ice-fall, for such it was, was the result of a steep place in the valley floor, and was produced in much the same way as a rapid or cascade is formed in a stream of water, except that ice broken into fragments, so to speak, by the more violent movement on the steep slope, takes longer to reunite than water under similar circumstances.

That it does eventually so reunite is proved by the fact that, a mile below, the surface of the glacier showed no signs of its tumultuous passage over the ice-fall, except that there was little rock débris on its surface, this having been engulfed by the crevasses amongst the *seracs.*

The ice-fall in the brilliant sunlight made a wonderful spectacle (Plate XIV.), but its passage was attended by much difficulty and danger. We had to proceed with the utmost caution, roped together, and cutting steps with our ice-axes at frequent intervals. Many times after a laborious ascent of a pinnacle, we found our road blocked by an impassable crevasse, and had to retrace our steps.

We had almost given up hope of being able to make our way on to the ice above the fall, and were seriously considering the alternative of climbing along the precipitous rocks on the side of the valley until the obstruction should be passed, when we were successful in finding our way through by means of an ice-bridge, a pinnacle which had fallen across the largest of the crevasses and had become firmly frozen into position. This saved us much trouble, as to find a route along those precipitous cliffs was, as we found on a subsequent occasion, both difficult and hazardous.

The surface of the ice above the fall was very similar to that below, except that at this higher level there was some fresh snow upon it, and in consequence we had to proceed with great caution to avoid concealed crevasses.

There were three rock-trains on this section of the glacier, one at each side and one near the centre. The central one consisted entirely of fragments of a peculiar granite containing large flakes of the white mica, muscovite, and on tracing it farther upstream we found that it originated in the centre of the glacier. At its point of origin there were only one or two blocks on the surface, but others could be seen through the ice a few inches below it, and it was evident that the rock was being picked up by the ice at some point below the surface, and being brought to light by the melting of the surface layers.

As we stood below the point of origin of the rock-train, looking towards the snowfield above, we noticed that to the right there was a small ice-fall which, however, only occupied half the width of the glacier, terminating at the rock-train, while the other half consisted of smooth ice. From this we concluded that to the right of the train was a concealed mass of rock over which the ice was breaking and from the end of which the material of the rock-train was being torn.

Near the rock-train on the side of the glacier remote from the small ice-fall was a stream of water flowing in a channel which it had cut in the ice. The channel contained a few boulders and here and there a little sand, but there could be no doubt that it was cut owing to the water being slightly above the freezing-point owing to absorption of solar heat, and on that account melting the ice of its bed. The channel was strikingly similar in form to some of those which we had observed in the plateau limestones near Lyell, which, it will be remembered, owed their origin to solution. Like the streams of the plateau, this river soon plunged below the surface and became lost to view, doubtless following some tunnel in the ice, or perhaps reaching its base and joining the sub-glacial river which emerged in the gorge near our camp.

At the point where the stream disappeared there was a funnel-shaped opening giving access to a vertical shaft whose depth it was impossible to determine with the means at our disposal.

There is this difference between the *moulins*, as these glacial funnels are called, and the sink holes of the limestone area; in the former case the medium in which they are cut is in motion, while the limestone is, of course, stationary. It might be thought that on this

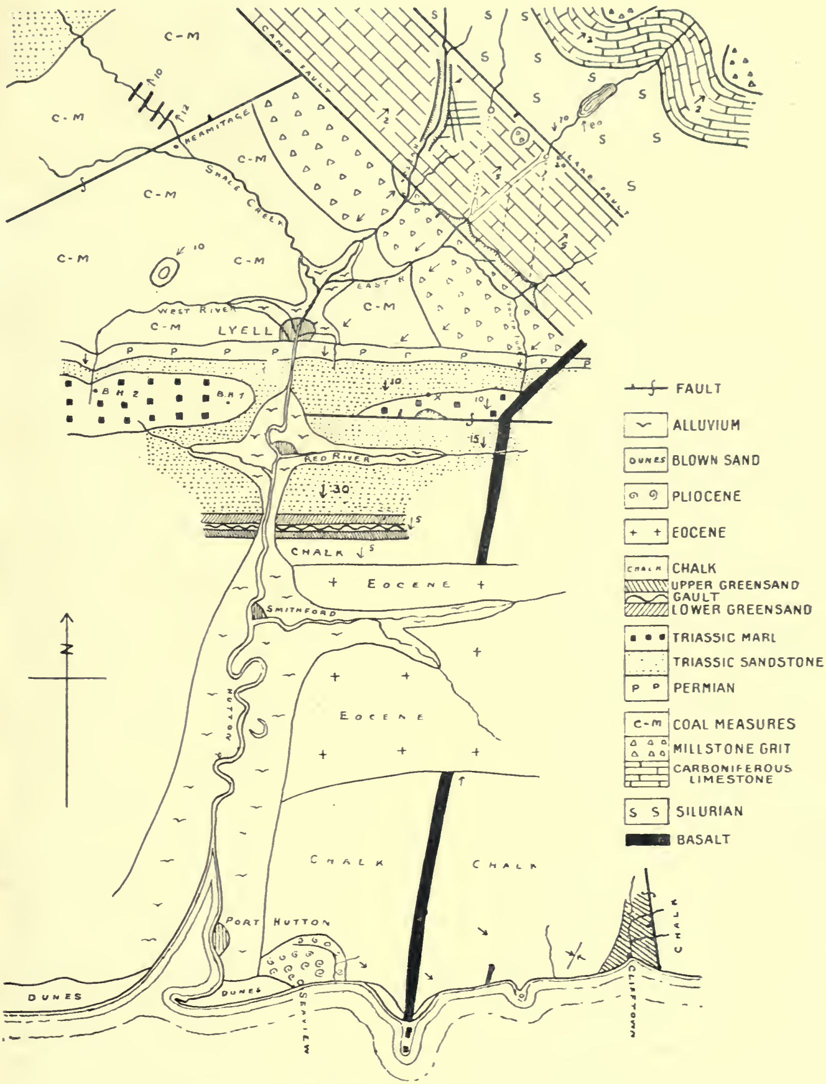

PLATE XV.—Map of Geologica South Sheet.

account the *moulins* would travel downstream with the ice, so that the stream would become elongated, and this doubtless happens to some slight extent.

No substantial change of locality occurs, however, as the original position of the *moulin* is determined by a tendency of the ice to fracture or crevasse in a definite position determined by a sudden change of slope in the rocky floor below. Thus, before the *moulin* has been carried far a new opening is produced in the old position, and this, of course, swallows the waters of the stream, leaving the lower part of the channel dry. Below our particular *moulin* was to be seen a string of hollows in the surface of the ice connected by the deserted and partially obliterated channel of the stream, and there could be no doubt that these represented successive positions of the water-sink. On following this line of deserted *moulins* it was found that they became less and less distinct as they were traced farther and farther down the stream, until eventually they were obliterated by the surface melting, the lower parts of the shafts having been long ago filled up by the flow of the ice.

On climbing still farther up the glacier we came upon another region of broken ice, but here, instead of the pointed *seracs* of the great ice-fall, we found great flat-topped masses separated by deep and altogether impassable crevasses, and beyond these, as we afterwards saw from the side of a neighbouring mountain, stretched a great snowfield, rising at a low angle, and from the surface of which there rose on the distant horizon several snowclad peaks. This appeared to be a great central snow-field filling this elevated basin amongst the mountains and supplying not only the glacier by which we had ascended, but several others which radiated from the central mass.

We were unable to determine whether the distant peaks marked the farther limit of the snowfield, but if this were the case we were very near the main watershed of the country. This was a question which we were obliged for the present to leave unsettled, as to penetrate farther into these snowclad wildernesses would require an expedition much better equipped than ours.

Having now spent five days and nights on and around the glacier, and having found that the great crevasses between us and the snowfield were really impassable, we made ready for our return to camp.

On this journey all went well until we reached the great ice-fall, where we at once got into difficulties. Our old steps which we had cut on the outward journey were still visible, but the crevasses had changed considerably during our absence, and eventually we reached the edge of a new crevasse 30 feet in width and could see the continuation of our tracks on its farther side. This, of course, brought us to a halt, but after some time we managed to work our way round the end of the rift and again take up our old track.

When, however, we reached the ice-bridge, by which we had crossed the great crevasse on our way up, we found to our consternation that it had fallen in, owing to a widening of the abyss, and all attempts to find another crossing proving fruitless, we slowly made our way back to the solid ice above the fall, and thence to the side of the glacier, with the object of taking to the rocks.

In a small recess of the mountain-side partly filled with moraine matter, we were able to make a dry though cold bivouac, in which to spend the night, as we must wait for a new day before commencing what might well be a long and tiring, if not perilous, climb. Our provisions were running low, and if we did not reach camp within the next thirty-six hours our stock would be completely exhausted.

Dawn saw us up and packing, and as soon as the light was sufficiently strong we set out to look for a route up the rocks. Luckily these were but little weathered—all loose material having been swept from their surfaces by the glacier at the time when it had reached these higher levels. There were thus numerous secure holds both for hands and feet, and, having found a ledge which ran along the face of the cliff in the direction in which we wished to go, we had great hopes of reaching the smooth ice below the fall early in the afternoon.

When we had followed this ledge for about half an hour it suddenly came to an end, and we were forced to climb 600 feet up a series of vertical rifts or chimneys, eventually finding ourselves on the higher slopes of the mountain, which were much less steep and well above the snow-line. Here travelling was easier in spite of the fact that the snow had become rather soft from the heat of the sun.

The sun was no longer shining on this particular slope and the snow became firmer as the afternoon advanced, but in spite of this it seemed probable that we should have to spend a night in the snow, as we could not as yet find any way down to the glacier, though we were now on that part of the mountain which overlooked the smooth ice below the fall. On rounding a corner we were delighted to see in front of us a long snow-slope extending down almost to the edge of the ice and terminating in a hollow among lateral moraines.

To glissade down the slope was a work of minutes, but we still had some rough work before us amongst the moraine ridges, and finally had to climb the side of the glacier by means of steps. Once we reached the surface of the glacier we knew that our troubles were over, and we were able to cross to its farther side and occupy the first bivouac of our outward journey, though we were unable to reach the camp until the following day at noon, having had no food since the previous night, when we had been on short rations.

After several days' rest we started for lower levels, having first examined the gravels associated with the moraines to see if they were gold-bearing.

We found no trace of gold nor yet of the pebbles of vein-quartz, and thus concluded that the rocks of this part of the range were not gold-bearing.

CHAPTER XVII

CENTRE VALLEY—TIN ORE

On our return journey we explored several tributary streams on both banks of the river; those on the right bank were all cut in the Archæan gneiss and the country which they drained consisted of rounded hills, heath-covered and devoid of crags. From the top of one of these hills we had a distant view of the volcanoes at the head of West Valley in one direction, and of the glacier we had just left on the other. From this elevated standpoint we were also able to obtain a better view than we had hitherto had of the great Granite Mountains to the north of the river, and we determined to make a thorough investigation of these before returning to Three Forks.

Accordingly we recrossed the river and ascended the tributary which joined it just below the upper lake. The lower part of the valley was excavated in gneiss and was, in many respects, similar to those of the tributaries on the right bank. Some little distance up the valley we came upon a great flat-topped terrace of gravel through which the stream had cut a deep channel; this terrace was surmounted by a second, which in its turn was followed by a third, though the last was smaller and less marked than the two lower ones.

On consulting the barometer we found that these terraces were approximately on the respective levels of the three dry overflow channels which we had previously observed on the spur of the hill which formed the southern boundary of the valley (see page 260), and we concluded that they had been formed as deltas in the glacier lake which had formerly occupied this site, each delta corresponding to a former water-level determined by the heights of the successive overflows.

At the mouth of the gorge cut by the stream in the lower terrace was a great fan of gravel, the result of the erosion of the terrace gravels. In this we found large and workable quantities of tin-stone (SnO_2) concentrated by the action of the stream in a manner similar to that in which the gold of Three Forks and the magnetite of East Valley had been accumulated.

Tin-stone is very hard and durable and is also considerably heavier than quartz and felspar, the other constituents of the deposits. Its specific gravity is about 7, while that of quartz is only 2·65 and that of felspar from 2·5 to 2·7. The ore occurred as small dark brown rounded grains, varying in size from that of a pea downwards, and was often to be seen in the gravel-fan constituting beds several inches in thickness. The whole deposit, however, covered less than half a square mile, and it appeared doubtful whether it would at present pay to work it, owing to the remoteness and inaccessibility of the district. The terrace gravels, which were much more extensive, also contained some tin-stone, but were not nearly so rich as the material of the fan.

All this tin-stone must have been derived from the rocks of the upper part of the valley, and we consequently followed the stream towards its source in the Granite Mountains, with a view to further investigations.

Above the terraces the valley was still in gneiss until the foot of the steep mountain slope was almost reached. About a mile from the foot of the mountain a change came over the appearance of the gneiss, it became much more friable and in places considerable quantities of black tourmaline were to be seen in it. This, so far as we could judge from the weathered specimens which were all that were available, seemed to have taken the place of the felspars.

A few hundreds of yards farther upstream we came across the junction of the gneiss with a granite similar to that which we had found as pebbles in Centre Valley. Close to its margin the granite was fine-grained and consisted largely of quartz and felspar, there being very little mica, but a little farther up the course of the stream it became coarser and was intersected by numerous veins or dykes of quartz and quartz-porphyry.

Before describing the complex of mineral veins which we found in the rocks of Granite Mountains, it may be well to give some account of mineral veins in general, and of the various views which are held as to their mode of origin. In the first place, the true mineral vein occupies a more or less vertical rift in either sedimentary, metamorphic, or igneous rocks, but is always definitely associated with the latter. It is generally believed that the veins are the result of the concentration of certain mineral matter, originally disseminated throughout the mass of the molten igneous magma.

We have already stated in Chapter IV that igneous rocks are composed for the most part of silicates, but there are also other bodies, such as oxides, sulphides, titanates, and phosphates, present in smaller quantities. It has been proved that a molten igneous magma is in reality a solution, and that it obeys the laws of ordinary solutions. Now it is a well-known fact that common substances as salt, sugar, saltpetre, and washing soda are much more soluble in hot than in cold water. If a hot saturated solution of one of them be made and allowed to cool, the solid will separate out as crystals, until only the quantity appropriate to the lower temperature will remain in solution. Finally, if the cooling be continued, the water itself will crystallize out as ice, and the whole mass will be solid. In cases of this kind it is customary to speak of the water as the solvent, and of the crystals as the dissolved substances, but there is really no difference in their condition when in complete solution, both are then in the liquid form, and their relationship is mutual.

Solutions of one liquid in another are also known, and in some instances there is no limit to their mutual solubility. For example, alcohol and water can be mixed in any proportion, and can only be separated by distillation.

Other liquids only dissolve in definite proportions, while others again are mutually insoluble. A very interesting example is to be found in the case of phenol (carbolic acid) and water. At temperatures of 68° Fahrenheit and over, these liquids can be mixed in all proportions, and if a mixture, say, half-and-half, be made at that temperature, and then allowed to cool, it will separate into two layers, one of which will consist of water with a little phenol, and the other of phenol with a little water, the relative quantities in each portion depending upon the temperature.

Both the above cases appear to occur in igneous magmas; thus, so far as we know, the various silicates when in the molten condition can mix in any proportions, but the same would not appear to be true of molten silicates and molten sulphides, which separate into separate liquids as the temperature of the magma falls.

There is a somewhat common association of a certain basic igneous rock called Norite, with the mineral Pyrrho tite, a sulphide of iron usually with some nickel. The ore nearly always occurs for the most part at the bottom of the igneous rock, and as it is much heavier than the molten silicates, its concentration as a separate liquid during cooling would account for this.

If several crystalline substances be dissolved together in hot water—compounds which have no chemical action upon each other being chosen—and the solution be slowly cooled, it will be found that the bodies will separate in a definite order, which will depend to some extent on the proportions of the various substances present, for it must be remembered that the presence of one substance in solution profoundly alters the degree of solubility of another. It must also be remembered that many substances which are gaseous at ordinary temperatures will dissolve in liquids, and so become themselves liquid.

It will thus be seen that the cooling of an igneous magma and the consequent formation of an igneous rock is a by no means simple matter, and that a very careful study of the rock mass is necessary before it is possible even to indicate the probable changes which took place during its solidification.

The magma consist chiefly of molten silicates of various elements, together with smaller quantities of oxides, sulphides, phosphates, and many other bodies, and also water and various gases.

The great masses of granite and other coarsely-crystalline igneous rocks can be proved to have solidified under a considerable cover of other rocks, and in some cases to have been later laid bare by the removal of this cover by denudation. It is with these vast masses of "Plutonic" rocks that the greater number of mineral veins are associated.

Let us now consider some of the possibilities which may occur during the cooling of a great magma at some depth below the surface of the ground. In the first place the cooling will be slow, as the thick cover of rocks will prevent the rapid escape of the heat. We will suppose the magma to be perfectly fluid, and at such a temperature that its constituents are freely miscible in all proportions.

As the temperature slowly falls it may be that the first action is a separation into two or more liquids (as in the case of the phenol and water), and then, as the temperature falls lower still, the various compounds of which the magma consists will commence to crystallize out in some definite order, dependent upon their relative solubility.

As the magma becomes solid the other substances in solution — the water, gases, and other volatile substances—will also be thrown out of solution, and, as they will be at temperatures far above their boiling points, will assume the gaseous form where space will allow, tending to force their way into any cracks which may occur in the enclosing rocks, upon which they may act chemically. As they reach cooler and cooler parts of the rocky cover, they will deposit various mineral substances.

This carriage of minerals as heated vapours, largely, in all probability, by the agency of superheated steam, is technically known as pneumatolysis, and it is believed to have given rise to a very numerous class of mineral veins.

Later in the history of the plutonic rock, when the temperature has fallen considerably, hot water and hot acid liquids take the place of the hot vapours, and continue the work of concentrating the mineral matters originally disseminated throughout the magma. This process is known as hydatogenesis, and is doubtless responsible for many mineral deposits.

To return now to the tin-bearing veins of the Granite Mountains, we must first consider their character and contents, and their relationship to the granite and to the gneiss which surrounds it, forming part of the original cover under which it solidified.

The granite where we first encountered it in the course of the stream was, as we have already stated, very fine-grained, but this was merely a marginal phase resulting from the rapid cooling of the edge of the mass. The typical granite, remote from its edge, consisted of quartz (SiO_2), Orthoclase Felspar ($KAlSi_3O_8$), Oligoclase Felspar ($CaAl_2Si_2O_8 \cdot 3NaAlSi_3O_8$), and Biotite Mica $(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$, with a few small crystals of tin-stone (SnO_2), Apatite ($3\{Ca_3(PO_4)_2\}CaF_2$), and Tourmaline (a complex boro-silicate of aluminium, iron, and magnesium).

Examining the surfaces of granite exposed in the mountain-side, we came across numerous veins of quartz containing masses of tin-stone. The quartz was arranged in crystals, having their greatest length at right angles to the sides of the vein, forming what is known as comby structure, while the tin-stone occupied the centre of the mass and varied in thickness from two to six inches. A section across the vein and the surrounding granite was as in Fig. 33. The granite on both sides of the vein

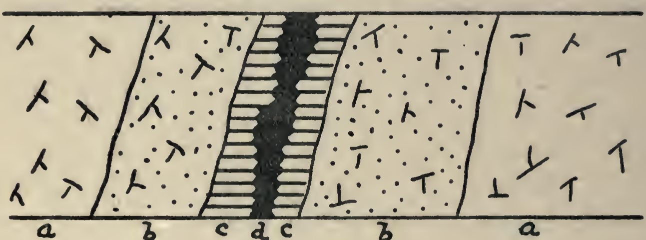

FIG. 33.—Section of Mineral Vein. *a*, Granite ; *b*, Greisen ; *c*, Quartz ; *d*, Ore.

had suffered considerable alteration, it was much harder than the general mass and contained much secondary quartz, Topaz $(Al,F)_2SiO_4$ and Fluorspar (CaF_2). This variety of altered granite is called greisen, and is constantly associated with tin veins. As will be seen, it throws much light on the mode of origin of the tin deposits themselves.

For some distance on each side of the zones of greisen, the granite is very soft and highly decomposed, the felspars having been converted into Kaolin probably by the action of steam and carbonic acid.

Always in connection with these deposits of tin and associated minerals there is much silicification of the rocks; that is to say, formation of secondary quartz.

Let us now consider how these changes have been brought about and how they are connected one with another. In the first place it must be noted that the rocks which form the walls of the veins are very much altered, and the nature of the alteration often gives valuable clues as to the mode of formation of the veins themselves.

The tin deposits are accompanied, as has been seen, by the formation of minerals containing fluorine, and it has been experimentally shown that at high temperatures the elements tin and fluorine form a compound SnF_4 which is volatile. At lower temperatures this fluoride of tin is chemically acted upon by water or steam, forming oxide of tin (tin-stone) and hydrofluoric acid, thus:—

$$SnF_4 + 2H_2O = SnO_2 + 4\,HF.$$

The hydrofluoric acid then acts upon the felspars and other minerals of the surrounding rocks, producing fluor-spar, topaz, and other fluorine-bearing minerals.

The secondary quartz (SiO_2) which is such a common feature of the rocks in the neighbourhood of tin veins and also of the veins themselves, in all probability in many instances is produced in a similar manner, as silicon also forms a volatile fluoride which is decomposed by water or steam, thus:—

$$SiF_4 + 2\,H_2O = SiO_2 + 4\,HF.$$

In cases where the element boron is also present the minerals axinite and tourmaline are formed, and of these the latter was present in considerable quantity in the Granite Mountains.

Carbonic acid also apparently played a part in the alterations, though probably, at a later stage, acting upon the felspars of the granite and producing Kaolin perhaps somewhat in the manner indicated by the following equation :—

$$\underset{\text{(Orthoclase)}}{Al_2O_3 . K_2O . 6(SiO_2)} + 2\,H_2O + CO_2 = \underset{\text{(Kaolin)}}{Al_2O_3 . 2(SiO_2) . 2H_2O} + 4\,SiO_2 + K_2CO_3$$

In this particular case the element lithium also seems to have been involved in the reactions, as with some of the veins was associated a considerable quantity of the lithia-mica, lepidolite. It would, therefore, appear that the tin, fluorine, and boron originally dissolved in the granite-magma were set free during its solidification at a stage when its outer parts had already become solid and that they found their way together with steam and carbonic acid along cracks and fissures which had been produced in the already solid portion.

Here as they reached cooler regions new combinations were entered into, the fluorides of tin and silicon were decomposed by the aqueous vapours forming the corresponding oxides tin-stone and quartz, while the hydrofluoric acid set free by this reaction combined with the minerals of the neighbouring rocks to form the characteristic minerals above described.

On tracing the mineral veins we found that though they traversed the granite and the surrounding gneiss, it was only near the junction of the two rocks that they were at all rich in tin.

We followed the foot of the mountains towards Tin Creek without again descending to Centre Valley, and all along the line of junction between the granite and the gneiss we found numerous rich tin-bearing veins. As we approached Tin Creek, however, a change came over the nature of the deposits, and in Tin Creek itself we found the following conditions prevailing. The veins were not so well marked, and both the granite and gneiss near the line of their junction appeared to have been crushed and fractured. They had been largely converted into greisen, and were intersected in all directions by thin veins of tin-stone associated with tourmaline and axinite.

It was from these wide areas of rock more or less impregnated throughout by tin-stone that the rich alluvial deposits of Tin Creek, presently to be described, had been derived.

Having passed the head of Tin Creek we proceeded to investigate the northern flank of the granite mass, but on this side there appeared to be fewer mineral veins, and these were not nearly so rich as the ones we had previously examined. We therefore returned to the head of Tin Creek, intending to make our way to the main valley by this route and to return to Three Forks Camp.

Having left the granite mass and entered the gneiss area, we encountered a large dyke of quartz-porphyry running nearly parallel to the stream. In this dyke many of the large felspar crystals had been entirely replaced by tin-stone, and there were considerable masses of secondary quartz containing needles of blue tourmaline. The gneisses in the neighbourhood of the dyke were in a highly decomposed condition and were wasting rapidly under the action of the weather.

The action of the streams had carried away most of the lighter minerals, resulting from the denudation of the granite and gneiss, but the tin-stone had been concentrated in every little pool and hollow of its bed, so that it could be gathered in large quantities even by hand. This promised to be the most easily workable portion of the tin-field, and could certainly be wrought at a handsome profit which might be used in opening up the rich veins on the south slope of the Granite Mountains.

The belt of weathered gneiss intersected by tin veins continued for some two miles from the edge of the granite mass, but became gradually more normal as the boundary was left behind. The excessive weathering of this belt of gneiss was the result of changes effected in its mineralogical character during the intrusion of the granite, both by the agency of heat and the action of the pneumatolytic gases.

The deposits of tin-stone were for the most part confined to this metamorphic aureole, though in the neighbourhood of some of the quartz-porphyry dykes considerable quantities occurred beyond its limits.

The investigation of these matters had carried us some distance to the east of Tin Creek, and we therefore determined to strike out across country for the head waters of Gold Creek, and to return by that stream instead of by the main valley.

On reaching Gold Creek, and travelling a few miles down its valley, we came upon a group of quartz-veins all bearing iron-pyrites and a little gold. These we were able to trace in a north-easterly direction until they entered and traversed an area of highly metamorphosed schists. A careful examination of this area failed to reveal the presence of any granite or other igneous rock at the surface, but the occurrence of the metamorphic rocks distinctly indicated the presence of such a rock at no great depth.

Nothing is known with certainty as to the way in which the gold is introduced into veins of this type, but its constant association with sulphides such as iron-pyrites points to the two substances having been carried simultaneously by the same agent. Very frequently the iron-pyrites is impregnated with small quantities of gold, and when it is remembered that gold is soluble in certain alkaline sulphides the connection appears closer still.

These quartz veins would certainly yield pay-ore, but they would, of course, require the erection of stamps for crushing the quartz before the gold could be extracted from it. It was, therefore, improbable that they would be worked while the rich alluvial fields below continued to yield.

Several other quartz veins were encountered on our way downstream between the group just described and those which we had seen on our previous visit, but none of them gave such good indications as those of the group.

On reaching the place where the rich deposits mentioned on page 241 had been found, we at once came across signs of habitation, and here we discovered our old prospector who had left our employ on the completion of the trial bore-holes near Lyell.

He had come up country with many others who had staked claims near Three Forks. He was not satisfied with the prospects there, and so had struck out for himself and rediscovered the only claim in the country, as it afterwards turned out, from which a fortune was made by a private digger.

He had now been working for about two months and had already accumulated a considerable hoard, and he calculated that should his claim continue to yield as at present he would be able to return to England a wealthy man by the end of the following year, even after having paid the somewhat heavy royalties imposed by the State.

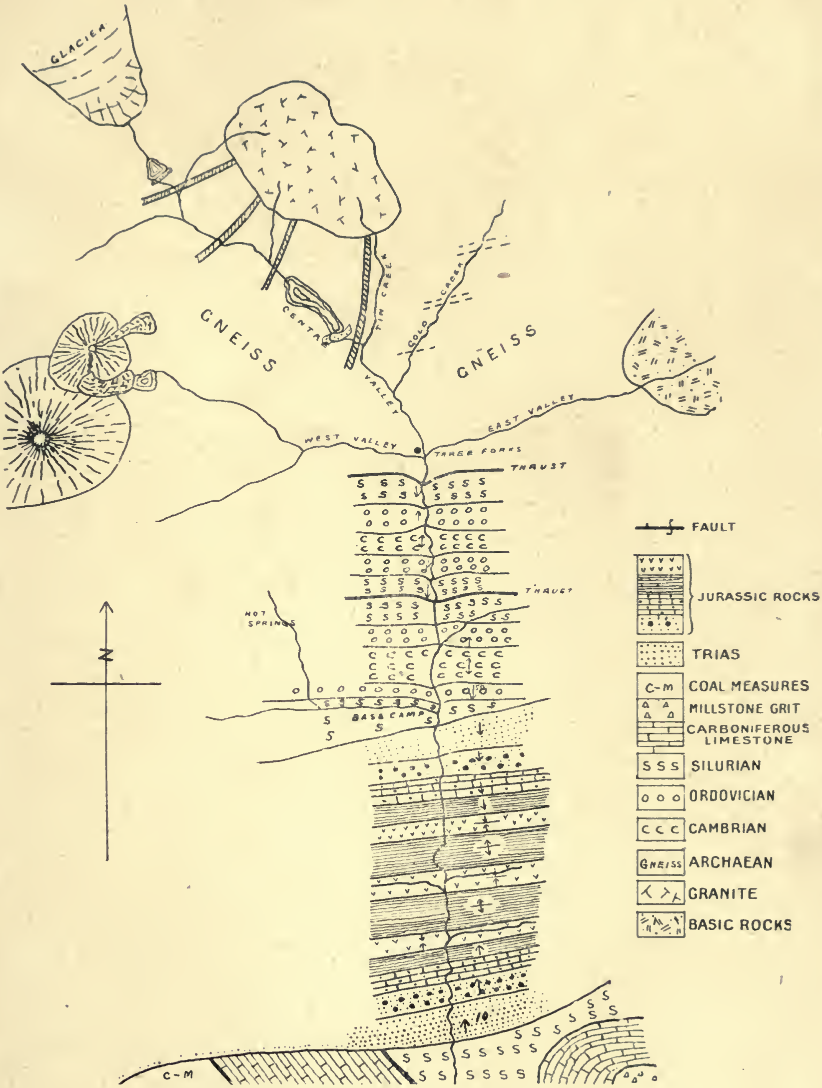

PLATE XVI.—Map of Geologica North Sheet.

CHAPTER XVIII

EAST VALLEY—CONCLUSION

It must not be supposed from the remarks at the end of the last chapter that the gold-field was not a success. In later years, when we revisited it, we found a thriving town on the site of our old camp at Three Forks, with shops, hotels, and public buildings, which bid fair to become the second most important town in the country.

The gold, though present in large quantity, was scattered through an enormous amount of sand and gravel and could only be worked by large companies having command of capital. The method of mining employed was as follows: First, reservoirs were constructed in the upper parts of the valleys of the mountain streams and pipes laid to convey the water to the scene of operations. Often this was a costly matter, as the reservoirs had to be constructed at such a height as to give an adequate head of water, which made it necessary in many instances to construct long pipe-lines for which all the materials had to be imported, as the iron industries of the Lyell coal-field were not yet sufficiently developed to supply the demand.

The water under high pressure was then distributed over the workings by means of pipes and delivered from nozzles, fastened down to stakes driven into the ground, against the banks of gravel. The water and the material thus washed down was then led through shallow troughs in the bottoms of which a number of grooves had been cut from side to side.

The quartz and other light minerals together with the finest of the gold-dust were carried away by the current while the coarser particles of gold were caught in the grooves and removed from time to time.

The tail waters from this arrangement were led through a second series of sluice-boxes in which the grooves were filled with mercury.

Gold being heavier than mercury, the fine dust which escaped from the upper boxes, of course, sank into the quicksilver, while the sand being lighter, remained on its surface and was washed away—the gold-dust dissolved in the mercury forming an amalgam from which it was recovered by distillation, the mercury being condensed and collected for further use.

In this way the finer part of the material washed out by the water jets was dealt with, but the coarser gravels brought down by the same process had to be handled with shovels and picked over by hand. A few small nuggets were thus obtained, but they formed but a small percentage of the total yield.

Some of the quartz pebbles which contained gold were put aside for subsequent treatment when a battery of stamps, now on its way up the river, should have arrived and been set up. There was no difficulty about power, as the Centre Valley River, though inadequate for hydraulic mining owing to lack of fall, was yet amply sufficient for working turbines. Indeed, a central electric power station and distributing apparatus had already been designed and was on its way up the river from Port Hutton.

A light railway was also under construction from Three Forks to the point where we had originally left our launches at Base Camp, and a small town was already growing up there. This would probably become of some considerable importance, as it would be here that the transhipment from barge to railway of all goods intended for Three Forks would take place, and consequently stores and warehouses would have to be erected.

In order to complete the preliminary survey of the district round Three Forks we had still to explore East Valley. It will be remembered that the sands at the foot of that valley contained large quantities of the mineral magnetite, from which we might conclude that rocks of a basic character occurred higher up the stream.

A careful examination of the sands showed that in addition to quartz and magnetite they contained grains of greenish chromite or chrome-iron ore. The presence of this ore pointed to the occurrence of extremely basic rocks, and about ten miles from the camp we came upon exposures of rocks belonging to the ultra-basic division.

In one of these, consisting for the most part of the mineral olivine (Mg_2SiO_4), there were masses of chromite which appeared to have segregated out from the remainder of the mass while cooling had been in progress.

Chromite segregations in ultra-basic rocks, such as that with which we were dealing, were known to us as frequently containing some of the rarer metals, and we consequently made a very careful examination of a large quantity of the material. In two instances we found minute grains of platinum, but a most thorough examination of the rocks themselves and of the sands derived from them failed to reveal further traces of that valuable metal.

Associated with the Dunite, the name given to the olivine-chromite rock, was another highly basic rock, Norite, and connected with this were mineral deposits which might prove to be of considerable value. These consisted of masses of Pyrrhotite, a sulphide of iron with some nickel, Pentlandite, a sulphide of nickel with some iron, and Copper Pyrites ($CuFeS_2$).

There were several other varieties of basic igneous rocks to be seen in the same district, and some of these contained considerable quantities of magnetite and a somewhat similar ore of iron containing titanium, Ilmenite.

These deposits should if they were sufficiently extensive be worth the attention of the iron smelters, but so complicated was the structure of this part of the country that the only way of working it out in a satisfactory manner would be by detailed mapping, and as time did not allow of this the further investigation of East Valley and its possible economic products was postponed until a subsequent occasion.

We next returned to Three Forks and spent some weeks in advising the engineers as to which parts of the gravels we considered most likely to yield well and upon similar matters. This done we set out for Base Camp *en route* for the oil-field, from which had come rumours of some general success, though no particulars were forthcoming.

At Base Camp we met with the captain of our launch, who had been employed during our absence in carrying various parties of engineers and others in the employ of the Government up and down the river, and ascertained from him that he would be ready to take us down to the oil region in two days' time.

Our discovery of gold and other minerals had, as is usual, brought about an epidemic of what one might call prospecting-fever, and many farmers and others had come up the river and started excavations in most unlikely places. There were, however, a number of foreign prospectors who knew more about the business, and a party of these had been working in the mountains between Base Camp and Three Forks. They had found small quantities of auriferous alluvium in certain parts of this section of the valley, but the gold was not in paying quantities. They had therefore turned their attention to the mountains, and had up to the present located two veins of Copper Pyrites, of which we saw samples in Base Camp.

When we arrived at the oil-field we were first taken to the southern anticline, where three bore-holes had been sunk without result. A fourth, however, had tapped a supply of natural gas which had been successfully capped. The gas was under high pressure, and as this did not appreciably fall when allowed to blow off freely for twenty-four hours, it seemed probable that there was a very large supply.

Valuable as this supply might have been had it been found in the neighbourhood of Lyell, or of one of the other large towns, it was of little use here in the wilderness. A pipe line even to Base Camp would cost so much in establishment and upkeep that the gas would not be able to compete successfully with electricity derived from water power. It was desirable, however, to conserve this supply, as in the event of the discovery of oil in the neighbourhood it could be used in connection with the refinery works which would then become necessary.

We next visited the works on the northern anticline, which we had thought at the time of our first visit to be the more promising. Here detailed examination had shown that there were several deposits of asphaltum, and that in many places there was a strong odour of petroleum. Boring operations were in progress in a very promising spot, and small quantities of a thick heavy greenish oil had been obtained at a depth of 260 feet.

The boring was at the moment in a bed of shale, and there seemed every possibility of penetrating the thickest bed of oolitic limestone immediately below this. As this might yield a considerable flow, we thought it desirable to provide some storage for a possible rush of oil. Accordingly a large clay-lined tank was prepared lower down the slope and connected with the site of the borehole by a channel. While this work was in progress we thought it desirable to suspend operations on the borehole and also to make all the necessary arrangements for capping should a supply of oil under pressure be encountered.

It was well that this was done, as when work was resumed it was found that the level of the oil had risen considerably in the well, and that it was much thinner and lighter in colour than previously. This pointed to a supply making its way up from below and mixing with the thick oil from the upper bed already mentioned.

On penetrating the shale for a further 30 feet, there was a considerable escape of gas under high pressure, which warned the men to clear out of the way. They had just time to haul out the drill when the gas was followed by a gush of oil which spouted 30 feet into the air. This continued for two days before it was possible to get it under control, and by that time not only was our tank full, but about a million gallons had run to waste down the valley.

Large samples of the oil were collected, and these we took down to Lyell with us, so that they might be examined by experts with a view to determining what type of refinery plant would be most suitable. In the meantime boring operations were suspended until such time as arrangements could be made to deal with the oil produced.

We found on our return to Lyell that our salt works had just commenced to put their products on the market, and that they were turning out a very good quality of salt.

We next visited the Hermitage Coalfield and found that three mines had been started and were all yielding good quality coal, though as yet only in small quantities, as the necessary plant for dealing with a large output had not yet arrived on the scene.

Of considerable importance was the discovery of a seam of clay-ironstone and several beds of fire-clay, a commodity which was absent from the Coal Hill beds.

As the result of these additions to the products of the country Geologica would soon be producing its own iron and steel, and doubtless also making many other articles for which it was as yet dependent on imports.

One thing which struck us most forcibly on our return to Lyell was the changed attitude of the leading citizens towards science and scientific education. When we first arrived in the country there was little knowledge of, and practically no interest in, such matters outside the medical profession, but since we had been able to demonstrate so conclusively the value of science, not from a merely academic standpoint, but from the practical economic side, an agitation had been started in favour of better scientific education than had as yet been possible. This had already resulted in the foundation of a technical school in Lyell, and the introduction of a Bill in Parliament for the creation and State endowment of a University in which the Faculties of Medicine and Science were to take the leading position.

Much work of a highly interesting character was still before us, in the detailed mapping of the country, and this would doubtless lead to the discovery of many things of importance locally, and possibly also of new scientific principles which might in future be turned to the advantage and comfort of mankind.

Geologica was now in a fair way to become an important nation, and we hoped that we should be able in future years to add still further to its resources, and to encourage scientific education, without which no modern nation can hope to remain in the front rank.

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