with all those causes which we have just been considering, would place Europe under a glacial condition, while at the same time the temperature of the Southern Ocean would, in consequence of the enormous quantity of warm water received, have its temperature (already high from other causes) raised enormously. And what holds true in regard to the currents of the Atlantic holds also true, though perhaps not to the same extent, of the currents of the Pacific.

"If the breadth of the Gulf-stream be taken at 50 miles, its depth at 1000 feet, its mean velocity at 2 statute miles an hour, the temperature of the water when it leaves the Gulf at 65°, and the return current at 40° F.,[1] then, as has been shown in *Climate and Time*, chapter ii., the quantity of heat conveyed into the Atlantic by this stream is equal to one-fourth of all the heat received from the sun by that ocean from the Tropic of Cancer to the Arctic Circle.[2] From principles discussed at considerable length in the chapter referred to, it is shown that, but for the Gulf-stream and other currents, London would have a mean annual temperature 40° lower than at present.

"But there is still another cause which must be noticed:—a strong undercurrent of air *from* the north implies an equally strong upper current *to* the north. Now if the effect of the undercurrent would be to impel the warm water at the equator to the south, the effect of the upper current would be to carry the aqueous vapour formed at the equator to the north; the upper current, on reaching the snow and ice of temperate regions, would deposit its moisture in the form of snow; so that it is probable that, nowithstanding the great cold of the glacial epoch, the quantity of snow falling in the northern region would be enormous. This would be particularly the case during summer, when the earth would be in the perihelion and the heat at the equator great. The equator would be the furnace where evaporation would take place, and the snow and ice of temperate regions would act as a condenser.

"The foregoing considerations, as well as many others which might be stated, lead to the conclusion that, in order to raise the mean temperature of the globe, *water* should be placed along the equator, and not *land*, as was contended by Sir Charles Lyell and others. For if land be placed at the equator, the possibility of conveying the sun's heat from the equatorial regions by means of ocean currents is prevented."

Inter-Glacial Periods.—Allusion has already been made to the fact that there is accumulating evidence to show that changes of climate have been recurrent, and that this alternation or periodicity goes far to prove them to be due to some general or cosmical cause. Dr Croll has ingeniously shown that every long cold period in each hemisphere must have been interrupted by several shorter warm periods, and "when the one hemisphere," he says, "is under glaciation, the other is enjoying a warm and equable climate. But, owing to the precession of the equinoxes, the condition of things on the two hemispheres must be reversed every 10,000 years or so. When the solstice passes the aphelion, a contrary process commences; the snow and ice gradually begin to diminish on the cold hemisphere and to make their appearance on the other hemisphere. The glaciated hemisphere turns by degrees warmer, and the warm hemisphere colder, and this continues to go on for a period of ten or twelve thousand years, until the winter solstice reaches the perihelion. By this time the conditions of the two hemispheres have been reversed; the formerly glaciated hemisphere has now become the warm one, and the warm hemisphere the glaciated. The transference of the ice from the one hemisphere to the other continues as long as the eccentricity remains at a high value. It is probable that, during the warm inter-glacial periods, Greenland and the Arctic regions would be comparatively free from snow and ice, and enjoying a temperate and equable climate."

PART II.—GEOGNOSY:

AN INVESTIGATION OF THE MATERIALS OF THE EARTH'S SUBSTANCE.

Before we enter upon any discussion of the geological changes which our planet has undergone, it is needful first of all to study the materials of which the planet consists. It is from the evidence furnished by the nature and arrangement of these materials that geological history must be compiled.

Viewed in a broad way then, the earth may be considered as consisting of (1) two envelopes,—an outer one of gas completely surrounding the planet, and an inner one of water covering about three-fourths of the globe; and (2) a globe cool and solid on its surface but possessing a high internal temperature.

I. The Envelopes.

1. *The Atmosphere.*—The gaseous envelope to which the name of atmosphere is given extends at least to a distance of 40 or 45 miles from the earth's surface, perhaps in a state of extreme tenuity to a much greater height. But its thickness must necessarily vary with latitude and changes in atmospheric pressure; the layer of air lying over the poles is not so deep as that which surrounds the equator.

Geologically considered, the atmosphere presents itself as an agent of change by virtue of its composition and the chemical reactions which it effects, its varying temperature and consequent influence in expanding and contracting rocks, and its movements.

Many speculations have been made regarding the chemical composition of the atmosphere during former geological periods. There can indeed be no doubt that it must originally have differed very greatly from its present condition. The oxygen which now forms fully a half of the outer crust of the earth was originally doubtless part of the atmosphere. So, too, the vast beds of coal found all over the world, in geological formations of many different ages, represent so much carbonic acid once present in the air. The chlorides in the sea likewise were probably carried down out of the atmosphere in the primitive condensation of the aqueous vapour. It has often been suggested that during the Carboniferous period the atmosphere must have been warmer and with more aqueous vapour and carbonic acid in its composition than at the present day, to admit of so luxuriant a flora as that from which the coal seams were formed. There seems, however, to be at present no method of arriving at any certainty on this subject.

As now existing, the atmosphere is considered to be normally a mechanical mixture of nearly 4 volumes of nitrogen and 1 of oxygen, with a minute proportion of carbonic acid, and still smaller quantities of other substances. Expressed in a tabular form this composition is as follows:—

Nitrogen	79·00
Oxygen	20·96
Carbonic acid	0·04

These quantities are liable to some variation according to locality. On the sea, for example, the proportion of carbonic acid is said to average about 0·03. In the air of streets and houses the proportion of oxygen diminishes, while that of carbonic acid increases. According to the minute researches of Dr Angus Smith, very pure air should contain not less than 20·99 of oxygen, with 0·030 of carbonic acid; but he found impure air in Manchester to have only 20·21 of oxygen, while the proportion of carbonic acid in that city during fog was ascertained to rise sometimes to 0·0679, and in the pit of the theatre to the very large amount of 0 2734. Small as the percentage of carbonic acid in ordinary air may seem, yet the total amount of this gas in the

[1] Sir Wyville Thomson states that in May 1873 the *Challenger* expedition found the Gulf-stream, at the point where it was crossed, to be about 60 miles in width, 100 fathoms deep, and flowing at the rate of 3 knots per hour. This makes the volume of the stream one-fifth greater than the above estimate.

[2] The quantity of heat conveyed by the Gulf-stream for distribution is equal to 77,479,650,000,000,000,000 foot-pounds per day. The quantity received from the sun by the North Atlantic is 310,923,000,000,000,000,000 foot-pounds.

whole atmosphere probably exceeds what would be disengaged if all the vegetable and animal matter on the earth's surface were burnt.

The other substances present in much more minute quantities are gases, vapours, and solid particles. Of these by much the most important is the vapour of water, which is always present, but in very variable amount according to temperature, ranging from about 4 to a maximum of 16 grains in 1000 grains of air.[1] It is this vapour which condenses into dew, rain, hail, and snow. In assuming a visible form, and descending through the atmosphere, it takes up a minute quantity of air, and of the different substances which the air may contain. Being caught by the rain, and held in solution or suspension, these substances can be best examined by analysing rain-water. In this way ammonia, nitric, sulphurous, and sulphuric acids, chlorides, various salts, solid carbon, inorganic dust, and organic matter have been detected. M. J. J. Pierre found as the result of his analysis that in the neighbourhood of Caen, in France, a hectare of land receives annually from the atmosphere, by means of rain—

Chloride of sodium	37·5	kilogrammes.
" potassium	8·2	"
" magnesium	2·5	"
" calcium	1·8	"
Sulphate of soda	8·4	"
" potash	8·0	"
" lime	6·2	"
" magnesia	5·9	"

To these ingredients must be added traces of ammonia, various salts, and organic substances, besides others still undetermined.[2] The powerful oxidizing agent ozone is present in variable but always minute quantities in the air.

The comparatively small but by no means unimportant proportions of these various components of the atmosphere are much more liable than the more essential gases to great variations. Chloride of sodium, for instance, is, as might be expected, particularly abundant in the air bordering the sea. Nitric acid, ammonia, and sulphuric acid appear in the air of towns most conspicuously. The organic substances present in the air are sometimes living germs, such as probably often lead to the propagation of disease, and sometimes mere fine particles of dust derived from the bodies of living or dead organisms.[3]

2. *The Oceans.*—About three-fourths of the surface of the globe (or about 144,712,000 square miles) is covered by the irregular sheet of water known as the sea. Within the last ten years much new light has been thrown upon the depths, temperatures, and biological conditions of the ocean-basins, more particularly by the "Lightning," "Porcupine," and "Challenger" expeditions fitted out by the British Government. It has been ascertained that few parts of the Atlantic Ocean exceed 3000 fathoms, the deepest sounding obtained there being one taken about 100 miles north from the island of St Thomas, which gave 3875 fathoms, or rather less than 4½ miles. The Atlantic appears to have an average depth in its more open parts of from 2000 to 3000 fathoms or from about 2 to 3½ miles. In the Pacific Ocean the "Challenger" got soundings of 3950 and 4475 fathoms, or about 4½ and rather more than 5 miles. But these appear to mark exceptionally abyssal depressions, the average depth being, as in the Atlantic, between 2000 and 3000 fathoms. We may therefore assume, as probably not far from the truth, that the average depth of the ocean is about 2500 fathoms, or nearly 3 miles.

The water of the oceans is distinguished from the ordinary terrestrial waters by a higher specific gravity, and the presence of so large a proportion of saline ingredients as to impart a strongly salt taste. The average density of sea-water is about 1·026, but it varies slightly in different parts even of the same ocean. According to the recent observations of Mr J. Y. Buchanan during the "Challenger" expedition, some of the heaviest sea-water occurs in the pathway of the trade-winds of the North Atlantic, where evaporation must be comparatively rapid, a density of 1·02781 being registered. Where, however, large rivers enter the sea, or where there is much melting ice, the density diminishes; Mr Buchanan found among the broken ice of the Antarctic Ocean that it had sunk to 1·02418.[4]

The greater density of sea-water depends of course upon the salts which it contains in solution. There seems no reason to doubt that these salts are, in the main, parts of the original constitution of the sea, and thus that the sea has always been salt. It is also probable that, as in the case of the atmosphere, the composition of the ocean water has in former geological periods been very different from what it is now, and that it has acquired its present character only after many ages of slow change, and the abstraction of much mineral matter originally contained in it. There is evidence indeed among the geological formations that large quantities of lime, silica, chlorides, and sulphates have in the course of time been removed from the sea.[5]

But it is evident also that, whatever may have been the original composition of the oceans, they have for a vast section of geological time been constantly receiving mineral matter in solution from the land. Every spring, brook, and river removes various salts from the rocks over which it moves, and these substances, thus dissolved, eventually find their way into the sea. Consequently sea-water ought to contain more or less traceable proportions of every substance which the terrestrial waters can remove from the land, in short, of probably every element present in the outer shell of the globe, for there seems to be no constituent of this earth which may not, under certain circumstances, be held in solution in water. Moreover, unless there be some counteracting process to remove these mineral ingredients, the ocean water ought to be growing, insensibly perhaps, but still assuredly, salter, for the supply of saline matter from the land is incessant. It has been ascertained indeed, with some approach to certainty, that the salinity of the Baltic and Mediterranean is gradually increasing.[6]

The average proportion of saline constituents in the water of the great oceans far from land is about three and a half parts in every hundred of water. But in enclosed seas, receiving much fresh water, it is greatly reduced, while in those where evaporation predominates it is correspondingly augmented. Thus the Baltic water contains from one-seventh to nearly a half of the ordinary proportion in ocean water, while the Mediterranean contains sometimes one-sixth more than that proportion. The mineral constituents include the following average ratios of salts[7]:—

[1] The quantity of aqueous vapour depends upon the temperature, warm air being able to retain more than cold air. Air at a temperature of 10° C. is saturated when it contains 9·362 grammes of vapour in a cubic metre of air.

[2] *Chimie Agricole*, quoted by Dr Angus Smith, *Air and Rain*, p. 232.

[3] The air of towns is peculiarly rich in impurities, especially in manufacturing districts, where much coal is used. These impurities, however, though of serious consequence to the towns in a sanitary point of view, do not sensibly affect the general atmosphere, seeing that they are probably in great measure taken out of the air by rain, even in the districts which produce them. They possess, however, a special geological significance, and in this respect, too, have important economic bearings. See on this whole subject Dr Angus Smith's work already cited.

[4] Buchanan, *Proc. Roy. Soc.* (1876), vol. xxiv.

[5] Dr Sterry Hunt even supposes that the saline waters of Canada and the northern States derive their mineral ingredients from the salts still retained among the sediments and precipitates of the ancient sea in which the earlier Palæozoic rocks were deposited.—*Geological and Chemical Essays*, p. 104.

[6] Paul, in Watts's *Dictionary of Chemistry*, v. 1020.

[7] Bischof, *Chemical Geology*, i. 379.

	Percentage.
Chloride of sodium (common salt)	75·786
Chloride of magnesium	9·159
Chloride of potassium	3·657
Sulphate of lime (gypsum)	4·617
Sulphate of magnesia (Epsom salts)	5·597
Bromide of sodium	1·184
	100·000
Total percentage of salts in sea-water	3·527

Besides these chief ingredients, sea-water has yielded minute traces of iodine, fluorine, silica, phosphoric acid, carbonate of lime and magnesia, silver, lead, copper, arsenic. Doubtless more perfect analysis will greatly increase this list.

In addition to its salts sea-water always contains dissolved atmospheric gases. From the researches conducted during the voyage of the "Bonité" in the Atlantic and Indian Oceans it was estimated that the gases in 100 volumes of sea-water ranged from 1·85 to 3·04, or from two to three per cent. From observations made during the "Porcupine" cruise of 1868 it was inferred that the proportion of oxygen was greatest (25·1 per cent.) in the surface water, and least (19·5) in the bottom water, while that of carbonic acid was least at the top (20·7) and greatest (27·9) at the bottom, and that the action of the waves was partially to eliminate the latter gas and to increase the amount of oxygen. More recently, however, during the voyage of the "Challenger," Mr J. Y. Buchanan ascertained that the proportion of carbonic acid was always nearly the same for similar temperatures, the amount in the Atlantic surface water, between 20° and 25° C., being 0·0466 gramme per litre, and in the surface Pacific water 0·0268. He points out the curious fact that, according to his analyses, sea-water contains sometimes at least thirty times as much carbonic acid as an equal bulk of fresh water would do, and he traces the greater power of absorption to the presence of the sulphates.

II. The Solid Globe.

1. *General Considerations.*—Within the atmospheric and oceanic envelopes lies the inner solid globe. Reference has already been made to the comparative density of the planet among the other members of the solar system. In all speculation about the history of the earth, the density of the whole mass of the planet as compared with water—the standard to which the specific gravities of terrestrial bodies are referred—is a question of prime importance. Various methods have been employed for determining the earth's density. The deflexion of the plumb-line on either side of a mountain of known structure and density, the time of oscillation of the pendulum at great heights, at the sea-level, and in deep mines, the comparative force of gravitation as measured by the torsion balance—each of these processes has been tried with the following various results:—

Plumb-line experiments on Schiehallien (Maskelyne and Playfair) gave as the mean density of the earth	4·713
Do. on Arthur's Seat, Edinburgh, (James)	5·316
Pendulum experiments on Mont Cenis (Carlini and Giulio)	4·950
Do. in Harton coal-pit, Newcastle (Airy)	6·565
Torsion balance experiments (Cavendish)	5·480
Do. do. (Baily)	5·660

Though these observations are somewhat discrepant, we may feel satisfied that the globe has a mean density neither much more nor much less than 5·5; that is to say, it is five and a half times heavier than one of the same dimensions formed of pure water. Now the average density of the materials which compose the accessible portions of the earth is between 2·5 and 3; so that the mean density of the whole globe is about twice as much as that of its outer part. We might therefore infer that the inside consists of much heavier materials than the outside, and consequently that the mass of the planet must contain at least two dissimilar portions—an exterior lighter crust or rind, and an interior heavier nucleus. But the effect of pressure must necessarily increase the specific gravity of the interior as will be alluded to further on.

2. *The Crust.*—It was formerly a prevalent belief that the exterior and interior of the globe differed from each other to such an extent that, while the outer parts were cool and solid, the vastly more enormous inner part being intensely hot was more or less completely fluid. Hence the term "crust" was applied to the external rind in the usual sense of that word. This crust was variously computed to be 10, 15, 20 or more miles in thickness. For reasons which will be afterwards given, the idea of internal liquidity has been opposed by eminent physicists and is now abandoned by most geologists. The term "crust," however, continues to be used as a convenient word to denote the cool, upper, or outer layer of the earth's mass, accessible to human observation. It is in the structure and history of this crust that the main subjects of geological investigation are contained. It will therefore be fully treated of in the following parts of this article.

There are, however, some general views as to its composition and the arrangement of its materials, which may appropriately find a place in this preliminary section. Evidently our direct acquaintance with the chemical constitution of the globe must be limited to that of the crust, though by inference we may eventually reach highly probable conclusions regarding the constitution of the interior. Chemical research has discovered that sixty-four simple or as yet indecomposable bodies, called elements, in various proportions and compounds, constitute the accessible part of the crust. Of these, however, the great majority are comparatively of rare occurrence. The crust, so far as we can examine it, is mainly built up of about sixteen elements, which may be arranged in the two following groups, the most abundant bodies being placed first in each list:—

Metalloids.	Atomic Weight.	*Metals.*	Atomic Weight.
Oxygen	15·96	Aluminium	27·30
Silicon	28·00	Calcium	39·90
Carbon	11·97	Magnesium	23·94
Sulphur	31·98	Potassium	39·04
Hydrogen (really a metal)	1·00	Sodium	22·99
Chlorine	35·37	Iron	55·90
Phosphorus	30·96	Manganese	54·80
Fluorine	19·10	Barium	136·80

By far the most abundant and important of these elements is oxygen. It forms about 23 per cent. by weight of air, 88·88 per cent. of water, and about a half of all the rocks which compose the visible portion or "crust" of the globe. Another metalloid, silicon, comes next in abundance. It is always united with oxygen, forming the mineral silica which, either alone or in combination with various metallic bases as silicates, constitutes a half of all the known mass of the globe. Of the remaining metalloids carbon and sulphur sometimes occur in the free state, but usually in combination with oxygen or some base or metal. Chlorine and fluorine are found associated with metallic bases. Hydrogen is properly a metal, and occurs chiefly in combination with oxygen as the oxide, water. Phosphorus occurs with oxygen principally in phosphate of lime.

Of the metals by far the most important in the architecture of the exterior of the earth is aluminium. In conjunction with oxygen and silicon it forms the basis of most crystalline rocks. Calcium, magnesium, potassium, and sodium, combined with oxygen, enter largely into the composition of rocks. Iron is the great colouring material in nature, most of the yellow, brown, red, and green hues of

rocks being due to some of its combinations. The sixteen elements mentioned in the foregoing lists form about ninety-nine parts of the earth's crust; the other elements constitute only about a hundredth part, though they include gold, silver, copper, tin, lead, and the other useful metals, iron excepted.

It is clear then that, so far as accessible to our observation, the outer portion of our planet consists mainly of metalloids, and its metallic constituents have in great part entered into combination with oxygen, so that the atmosphere contains the residue of that gas which has not yet united itself to terrestrial compounds. In a broad view of the arrangement of the chemical elements in the external crust, the suggestive speculation of Durocher deserves attention.[1] He regarded all rocks as referable to two layers or magmas co-existing in the earth's crust the one beneath the other, according to their specific gravities. The upper or outer layer, which he termed the acid or siliceous magma, contains an excess of silica, and has a mean density of 2·65. The lower or inner layer, which he called the basic magma, has from six to eight times more of the earthy bases and iron oxides, with a mean density of 2·96. To the former he assigned the early plutonic rocks, granite, felsite, &c., with the more recent trachytes; to the latter he relegated all the heavy lavas, basalts, diorites, &c. The ratio of silica is 7 in the acid magma to 5 in the basic. Though the proportion of this acid or of the earthy and metallic bases cannot be regarded as any certain evidence of the geological date of rocks, nor of their probable depth of origin, it is nevertheless a fact that (with many important exceptions) the eruptive rocks of the older geological periods are very generally super-silicated and of lower specific gravity, while those of later time are very frequently poor in silica but rich in the earthy bases and in iron and manganese, with a consequent higher specific gravity. The latter, according to Durocher, have been forced up from a lower zone through the lighter siliceous crust.

3. *The Interior or Nucleus.*—Though we cannot hope ever to have direct acquaintance with more than the mere outside skin of our planet, we may be led to infer the irregular distribution of materials within the crust from the present distribution of land and water, and the observed differences in the amount of deflexion of the plumb-line near the sea and near mountain-chains. The fact that the southern hemisphere is almost wholly covered with water appears explicable only on the assumption of an excess of density in the mass of that portion of the planet. The existence of such a vast sheet of water as that of the Pacific Ocean is to be accounted for, says Archdeacon Pratt, by the presence of "some excess of matter in the solid parts of the earth between the Pacific Ocean and the earth's centre, which retains the water in its place, otherwise the ocean would flow away to the other parts of the earth."[2] The same writer points out that a deflexion of the plumb-line towards the sea, which has in a number of cases been observed, indicates that "the density of the crust beneath the mountains must be less than that below the plains, and still less than that below the ocean-bed."[3] Apart therefore from the depressions of the earth's surface in which the oceans lie, we must regard the internal density, whether of crust or nucleus, to be somewhat irregularly arranged,—there being an excess of heavy materials in the water hemisphere and beneath the ocean-beds as compared with the continental masses.

In our ignorance regarding the chemical constitution of the nucleus of our planet, an argument has sometimes been based upon the known fact that the specific gravity of that nucleus is about double that of the crust. This has been held by some writers to prove that the interior must consist of much heavier material, and is therefore probably metallic. But in so reasoning they forget that the effect of pressure ought to make the density of the nucleus much higher, even if the interior consisted of matter no heavier than the crust. In fact, we might argue for the probable comparative lightness of the substance composing the nucleus. That the total density of the planet does not greatly exceed its observed amount seems only explicable on the supposition that some antagonistic force counteracts the effects of pressure. The only force we can suppose capable of so acting is heat. But how and to what extent this counterbalancing takes place is still unknown.

If we regard the question from another point of view, however, the idea of a metallic nucleus seems not improbable. When the materials of the globe existed in a fluid condition, as they are usually supposed to have done, they would doubtless arrange themselves in accordance with their relative specific gravities. The denser elements would sink towards the centre, the lighter would remain outside. That this distribution has certainly taken place to some extent is evident from the structure of the envelopes and crust. It is what might be expected if the constitution of the globe resembles on a small scale the larger planetary system of which it forms a part. The existence of a metallic interior has always been inferred from the metalliferous veins which traverse the crust, and which are commonly supposed to have been filled from below.

Admitting the possibility or even probability of a metallic nucleus, in spite of the comparatively low density of the globe as a whole, we might speculate further as to the arrangement of the denser internal materials. The late Mr David Forbes suggested that the planet might be supposed to consist of three layers of uniform densities, enclosed one within the other, the density increasing towards the centre in arithmetical progression. Allowing 2·5 as the specific gravity of the crust or outer layer, he assigned 12·0 or thereabouts as that of the middle layer, and supposed that the inner nucleus might possess one averaging 20·0.[4] Materials do not yet exist for any satisfactory conclusions on his subject.

In the evidence obtainable as to the former history of the earth, no fact is of more importance than the existence of a high temperature beneath the crust, which has now been placed beyond all doubt. This feature of the planet's organization is made clear by the following proofs:—

(1.) *Volcanoes.*—In many regions of the earth's surface openings exist from which steam and hot vapours, ashes and streams of molten rock are from time to time emitted. The abundance of these openings seems inexplicable by any mere local causes, but must be regarded as indicative of a very high internal temperature. If to the still active vents of eruption we add those which have formerly been the channels of communication between the interior and the surface, there are probably few large regions of the globe where proofs of volcanic action cannot be found. Everywhere we meet with masses of molten rock which have risen from below as if from some general reservoir.

(2.) *Hot Springs.*—Where volcanic eruptions have ceased, evidence of a high internal temperature is still often to be found in springs of hot water which continue for centuries to maintain their heat. Thermal springs, however, are not confined to volcanic districts. They sometimes rise even in regions many hundreds of miles distant from any active volcanic vent. The hot springs of Bath (temp. 120° Fahr.) and Buxton (temp. 82° Fahr.) in England are

[1] Translated by Haughton in his *Manual of Geology*, 1866, p. 16.
[2] *Figure of the Earth*, 4th edit., p. 236.
[3] *Op. cit.*, p. 200. See also Herschel, *Phys. Geog.*; and O. Fisher, *Cambridge Phil. Trans.*, xii., part ii.
[4] *Popular Science Review*, April 1869.

fully 900 miles from the Icelandic volcanoes on the one side, and 1100 miles from those of Italy and Sicily on the other.

(3.) *Borings, Wells, and Mines.*—The influence of the seasonal changes of temperature extends downward from the surface to a depth which varies according to latitude, to the thermal conductivity of the soils and rocks, and perhaps to other causes. The cold of winter and the heat of summer may be regarded as following each other in successive waves downward, until they disappear along a limit at which the temperature remains constant. This zone of invariable temperature is commonly believed to lie somewhere between 60 and 80 feet down in temperate regions. At Yakutsk in eastern Siberia (lat. 62° N.), however, the soil is permanently frozen to a depth of about 700 feet.[1] In Java, on the other hand, a constant temperature is said to be met with at a depth of only 2 or 3 feet.[2]

It is a remarkable fact, now verified by observation all over the world, that below the limit of the influence of ordinary seasonal changes the temperature, so far as we yet know, is nowhere found to diminish downwards. It always rises; and its rate of increment never falls much below the average. The only exceptional cases occur under circumstances not difficult of explanation. On the one hand, the neighbourhood of hot-springs, of large masses of lava, or of other manifestations of volcanic activity, may raise the subterranean temperature much above its normal condition; and this augmentation may not disappear for many thousand years after the volcanic activity has wholly ceased, since the cooling down of a subterranean mass of lava would necessarily be a very slow process. On the other hand, the spread of a thick mass of snow and ice over any considerable area of the earth's surface, and its continuance there for several thousand years, would so depress the subterranean isothermals that for many centuries afterwards there might be a fall of temperature for a certain distance downwards. At the present day, in at least the more northerly parts of the northern hemisphere, there are such evidences of a former more rigorous climate, as in the well sinking at Yakutsk already referred to.[3] Sir William Thomson[4] has calculated that any considerable area of the earth's surface covered for several thousand years by snow or ice, and retaining, after the disappearance of that frozen covering, an average surface temperature of 13° C., "would during 900 years show a decreasing temperature for some depth down from the surface, and 3600 years after the clearing away of the ice would still show residual effect of the ancient cold, in a half rate of augmentation of temperature downwards in the upper strata, gradually increasing to the whole normal rate, which would be sensibly reached at a depth of 600 metres." But beneath the limit to which the influence of the changes of the seasons extends, observations in most parts of the globe show that the temperature invariably rises as we penetrate towards the interior of the earth. According to present knowledge the average rate of increase amounts to 1° Fahr. for every 50 or 60 feet of descent, and this rise is found whether the boring be made at the sea-level or on elevated ground. The subjoined table gives the results of temperature observations at widely separated localties[5]:—

[1] Helmersen, *Brit. Assoc. Report*, 1871.
[2] Junghuhn's *Java*, ii. p. 771.
[3] Professor Prestwich (*Inaugural Lecture*, 1875, p. 45) has suggested that to the more rapid refrigeration of the earth's surface during this cold period, and to the consequent depression of the subterraneous isothermal lines, the alleged present comparative quietude of the volcanic forces is to be attributed, the internal heat not having yet recovered its dominion in the outer crust.
[4] *Brit. Assoc. Reports*, 1876, Sections, p. 3.
[5] See "Reports of Committee on Underground Temperature," *Brit. Assoc. Rep.* from 1868 to 1877.

			Feet
Dukinfield, near Manchester (2040 ft., coal measures)	1° Fahr.	for every	83·2
Rose Bridge, Wigan (2445 ft., coal measures)	,,	,,	54·9
South Balgray, Glasgow (525 ft., coal measures)	,,	,,	41
Kentish Town, London (1100 ft., London clay, chalk, gault, &c.)	,,	,,	54·6
La Chapelle, Paris (660 metres, chalk, &c.)	,,	,,	84
Grenelle Well, Paris (1795·6 ft., do.)	,,	,,	56·9
St André, do. (263 metres, do.)	,,	,,	56·4
Neu Salzwerk boring, Westphalia (2281 ft.)	,,	,,	54·68
Mendorff bore, near Luxembourg (2394 ft.)	,,	,,	57·0
Bore near Geneva	,,	,,	55
Mont Cenis tunnel (5280 ft. below summit of Mount Frejus, metamorphic rocks)	,,	,, (?)	81
Yakutsk, Siberia, (656 ft., limestone, &c., and granite)	,,	,,	60

(4.) *Irregularities in the Downward Increment of Heat.*—While these examples prove a progressive increase of temperature, they show also that this rate of increase is not strictly uniform. The more detailed observations which have been made in recent years have brought to light the important fact that considerable variations in the rate of increase take place even in the same bore. If, for instance, we examine the temperatures obtained at different depths in the Rose Bridge colliery shaft cited in the foregoing list, we find them to read as in the following columns:—

Depth in Yards.	Temperature (Fahr.).	Depth in Yards.	Temperature (Fahr.).
558	78	745	89
605	80	761	90½
630	83	775	91½
663	85	783	92
671	86	800	93
679	87	806	93½
734	88½	815	94

At La Chapelle, in an important well made for the water-supply of Paris, observations have been taken of the temperature at different depths, as shown in the subjoined table[6]:—

Depth in Metres.	Temperature (Fahr.).	Depth in Metres.	Temperature (Fahr.)
100	59·5	500	72·6
200	61·8	600	75·0
300	65·5	660	76·0
400	69·0		

In drawing attention to the temperature-observations at the Rose Bridge colliery—the deepest mine in Great Britain—Professor Everett points out that, assuming the surface temperature to be 49° Fahr., in the first 558 yards the rate of rise of temperature is 1° for 57·7 feet; in the next 257 yards it is 1° in 48·2 feet; in the portion between 605 and 671 yards—a distance of only 198 feet—it is 1° in 33 feet; in the lowest portion of 432 feet it is 1° in 54 feet.[7] When such irregularities occur in the same vertical shaft, it is not surprising that the average should vary so much in different places.

There can be little doubt that one main cause of these variations is to be sought in the different thermal conductivities of the rocks of the earth's crust. The first accurate measurements of the conducting powers of rocks were made by the late Professor J. D. Forbes at Edinburgh (1837–1845). He selected three sites for his thermometers, one in "trap-rock" (a porphyrite of Lower Carboniferous age), one in loose sand, and one in sandstone, each instrument being sunk to a depth of 24 French feet from the surface. He found that the wave of summer heat reached the first instrument on 4th January, the second on 25th December, and the third on 3d November, the trap-rock being by far the worst conductor, and the solid sandstone by far the best.[8]

The British Association has recently appointed a committee to investigate this subject in greater detail. Already some important determinations have been made by it regarding the absolute conductivity of various rocks. As a rule the lighter and more porous rocks offer the greatest

[6] "Report of Committee on Underground Temperature," *Brit. Assoc. Rep.*, 1873, p. 254.
[7] "Report of Committee on Underground Temperature," *Brit. Assoc. Rep.* for 1870, p. 31.
[8] *Trans. Roy. Soc. Edin.*, xvi. 180.

resistance to the passage of heat, while the more dense and crystalline offer the least resistance. The resistance of opaque white quartz is expressed by the number 114, that of basalt by 273, while that of cannel coal stands very much higher at 1538, or more than thirteen times that of quartz.[1]

It is evident also that, from the texture and structure of most rocks, the conductivity must vary in different directions through the same mass, heat being more easily conducted along than across the "grain," the bedding, and the other numerous divisional surfaces. Experiments have been made to determine these variations in a number of rocks. Thus, the conductivity in a direction transverse to the divisional planes being taken as unity, the conductivity parallel with these planes was found in a variety of magnesian schist to be 4·028. In certain slates and schistose rocks from central France the ratio varied from 1 : 2·56 to 1 : 3·952. Hence in such fissile rocks as slate and mica-schist heat may travel four times more easily along the lines of cleavage or foliation than across them.[2]

In reasoning upon the discrepancies in the rate of increase of subterranean temperatures, we must also bear in mind that certain kinds of rock are more liable than others to be charged with water, and that, in almost every boring or shaft, one or more horizons of such water-bearing rocks are met with. The effect of this interstitial water is to diminish thermal resistance. Dry red brick has its resistance lowered from 680 to 405 by being thoroughly soaked in water, its conductivity being thus increased 68 per cent. A piece of sandstone has its conductivity heightened to the extent of 8 per cent. by being wetted.[3]

Mr Mallet has contended that the variations in the amount of increase in subterranean temperature are too great to permit us to believe them to be due merely to differences in the transmission of the general internal heat, and that they point to local accessions of heat arising from transformation of the mechanical work of compression, which is due to the constant cooling and contraction of the globe.[4] But it may be replied that these variations are not greater than, from the known divergences in the conductivities of rocks, they might fairly be expected to be.

(5.) *Probable Condition of the Earth's Interior.*—Various theories (mostly fanciful) have been propounded on this subject. There are only three which merit serious consideration. (1.) One of these supposes the planet to consist of a solid crust and a molten interior. (2.) The second holds that, with the exception of local vesicular spaces, the globe is solid and rigid to the centre. (3.) The third contends that, while the mass of the globe is solid, there lies a liquid substratum beneath the crust.

1. The arguments in favour of internal liquidity may be summed up as follows. (*a.*) The ascertained rise of temperature inwards from the surface is such that, at a very moderate depth, the ordinary melting point of even the most refractory substances would be reached. At 20 miles the temperature, if it increases progressively, as it does in the depths accessible to observation, must be about 1760° Fahr.; at 50 miles it must be 4600°, or far higher than the fusing-point even of so stubborn a metal as platinum, which melts at 3080° Fahr. (*b.*) All over the world volcanoes exist from which steam and torrents of molten lava are from time to time erupted. Abundant as are the active volcanic vents, they form but a small proportion of the whole which have been in operation since early geological time. It has been inferred therefore that these numerous funnels of

[1] Herschel and Lebour, *Brit. Assoc. Rep.*, 1875, p. 59.
[2] Jannettaz, *Bull. Soc. Géol. de France* (April–June, 1874), tom. ii. p. 264; "Report of Committee on Thermal Conductivities of Rock," *Brit. Assoc. Rep.*, 1875, p. 61.
[3] Herschel and Lebour, *Brit. Assoc. Rep.*, 1875, p. 58.
[4] "Volcanic Energy," *Phil. Trans.*, 1875.

communication with the heated interior could not have existed and poured forth such a vast amount of molten rock, unless they drew their supplies from an immense internal molten nucleus. (*c.*) When the products of volcanic action from different and widely-separated regions are compared and analysed, they are found to exhibit a remarkable uniformity of character. Lavas from Vesuvius, from Hecla, from the Andes, from Japan, and from New Zealand present such an agreement in essential particulars as, it is contended, can only be accounted for on the supposition that they have all emanated from one vast common source.[5] (*d.*) The abundant earthquake shocks which affect large areas of the globe are maintained to be inexplicable unless on the supposition of the existence of a thin and somewhat flexible crust. These arguments, it will be observed, are only of the nature of inferences drawn from observations of the present constitution of the globe. They are based on geological data, and have been frequently urged by geologists as supporting the only view of the nature of the earth's interior compatible with geological evidence.

2. The arguments against the internal fluidity of the earth are based on physical and astronomical considerations of the greatest importance. They may be arranged as follows:—

(*a.*) Argument from precession and nutation.—The problem of the internal condition of the globe was attacked as far back as the year 1839 by the late Mr Hopkins of Cambridge, who endeavoured to calculate how far the planetary motions of precession and nutation would be influenced by the solidity or liquidity of the earth's interior. He found that the precessional and nutational movements could not possibly be as they are if the planet consisted of a central ocean of molten rock surrounded with a crust of 20 or 30 miles in thickness, that the least possible thickness of crust consistent with the existing movements was from 800 to 1000 miles, and that the whole might even be solid to the centre, with the exception of comparatively small vesicular spaces filled with melted rock.[6]

M. Delaunay, in a paper on *The Hypothesis of the Interior Fluidity of the Globe*,[7] threw doubt on Hopkins's views, and suggested that, if the interior were a mass of sufficient viscosity, it might behave as if it were a solid, and thus the phenomenon of precession and nutation might not be affected. Sir William Thomson, who had already arrived at the conclusion that the interior of the globe must be solid, and acquiesced generally in Hopkins's conclusions, pointed out that M. Delaunay had not worked out the problem mathematically, otherwise he could not have failed to see that the hypothesis of a viscous and quasi-rigid interior "breaks down when tested by a simple calculation of the amount of tangential force required to give to any globular portion of the interior mass the precessional and nutational motions which, with other physical astronomers, he attributes to the earth as a whole."[8] Sir William, in making this calculation, holds that it demonstrates the earth's crust down to depths of hundreds of kilometres to be capable of resisting such a tangential stress (amounting to nearly $\frac{1}{10}$th of a gramme weight per square centimetre) as would with great rapidity draw out of shape any plastic substance which could properly be termed a viscous fluid. "An angular distortion of 8″ is produced in a cube of glass by a distorting stress of about ten grammes weight per square centimetre. We may therefore safely conclude that the rigidity of the earth's interior substance could not be less than a millionth of the rigidity of glass without very sensibly augmenting the lunar nineteen-yearly nutation."[9]

[5] See D. Forbes, "On the Nature of the Interior of the Earth," *Popular Science Review*, April 1869.
[6] *Phil. Trans.*, 1839; *Researches in Physical Geology*, 1839–1842; *Brit. Assoc. Rep.*, 1847.
[7] *Comptes Rendus*, July 13, 1868.
[8] *Nature*, February 1, 1872.
[9] *Loc. cit.*, p. 258.

In Hopkins's hypothesis he assumed the crust to be infinitely rigid and unyielding, which is not true of any material substance. Sir William Thomson has recently returned to the problem, in the light of his own researches in vortex-motion. He now finds that, while the argument against a thin crust and vast liquid interior is still invincible, the phenomena of precession and nutation do not decisively settle the question of internal fluidity, though the solar semi-annual and lunar fortnightly nutations absolutely disprove the existence of a thin rigid shell full of liquid. If the inner surface of the crust or shell were rigorously spherical, the interior mass of supposed liquid could experience no precessional or nutational influence, except in so far as, if heterogeneous in composition, it might suffer from external attraction due to non-sphericity of its surfaces of equal density. But "a very slight deviation of the inner surface of the shell from perfect sphericity would suffice, in virtue of the quasi-rigidity due to vortex-motion, to hold back the shell from taking sensibly more precession than it would give to the liquid, and to cause the liquid (homogeneous or heterogeneous) and the shell to have sensibly the same precessional motion as if the whole constituted one rigid body."[1]

The assumption of a comparatively thin crust requires that the crust shall have such perfect rigidity as is possessed by no known substance. The tide-producing force of the moon and sun exerts such a strain upon the substance of the globe that it seems in the highest degree improbable that the planet could maintain its shape as it does unless the supposed crust were at least 2000 or 2500 miles in thickness.[2] That the solid mass of the earth must yield to this strain is certain, though the amount of deformation is so slight as to have hitherto escaped all attempts to detect it. Had the rigidity been even that of glass or of steel, the deformation would probably have been by this time detected, and the actual phenomena of precession and nutation, as well as of the tides, would then have been very sensibly diminished.[3] The conclusion is thus reached that the mass of the earth "is on the whole more rigid certainly than a continuous solid globe of glass of the same diameter."[4]

(*b.*) Argument from the tides.—The phenómena of the oceanic tides are only explicable on the theory that the earth is either solid to the centre, or possesses so thick a crust (2500 miles or more) as to give to the planet practical solidity. Sir William Thomson remarks that, "were the crust of continuous steel, and 500 kilometres thick, it would yield very nearly as much as if it were india-rubber to the deforming influences of centrifugal force, and of the sun's and moon's attractions." It would yield, indeed, so freely to these attractions "that it would simply carry the waters of the ocean up and down with it, and there would be no sensible tidal rise and fall of water relatively to land."[5] Mr George H. Darwin has recently investigated mathematically the bodily tides of viscous and semi-elastic spheroids, and the character of the ocean tides on a yielding nucleus.[6] His results tend to increase the force of Sir William Thomson's argument, since they show that "no very considerable portion of the interior of the earth can even distantly approach the fluid condition," the effective rigidity of the whole globe being very great.

(*c.*) Argument from relative densities of melted and solid rock.—The two preceding arguments must be considered decisive against the hypothesis of a thin shell or crust covering a nucleus of molten matter. It has been further urged, however, as an objection to this hypothesis, that cold solid rock is necessarily more dense than hot melted rock, and that even if a thin crust were formed over the central molten globe it would immediately break up and the fragments would sink towards the centre.[7] Undoubtedly this would happen were the material of the earth's mass of the same density throughout. But, as has been already pointed out, the specific gravity of the interior is at least twice as much as that of the visible parts of the crust. If this difference be due, not merely to the effect of pressure, but to the presence in the interior of intensely heated metallic substances, we cannot suppose that solidified portions of such rocks as granite and the various lavas could ever have sunk into the centre of the earth, so as to build up there the honey-combed cavernous mass which might have served as a nucleus in the ultimate solidification of the whole planet. From the considerations above advanced we have seen that the earth's central mass may be plausibly conjectured to be metallic. Into this dense central mass the comparatively light crust could not sink, though its earliest formed portions would no doubt descend until they reached a stratum with specific gravity agreeing with their own, or until they were again melted.[8]

3. The ingenious suggestion of Mr Fisher, already cited (*ante*, p. 217), in favour of the existence of a possible fluid or viscous substratum between the flexible outer shell and an inner rigid nucleus, is made with the view of reconciling the requirements of physics with those facts in geology which seem to demand the existence of a mobile mass of intensely hot matter at no great depth beneath the surface. Whether it does so must be left for physicists to decide. But, on geological grounds, it may be questioned whether such a fluid substratum is needed. We must bear in mind that the land of the globe, regarding the geological structure of which alone we know anything, covers but a small part of the whole surface of the planet; that the existing continents seem from earliest times to have specially suffered from the reaction between the heated interior and the cooled exterior, forming, as it were, lines of relief from the strain of compression; and that along such lines, if the substance of the interior be everywhere just about the melting point, relief from pressure by corrugation would cause liquefaction of the matter so relieved, and its ascent towards the surface; so that evidences of volcanic action on the terrestrial ridges might be expected to occur, and to be referable to all ages. Mr Fisher assumes the contraction of rock in cooling to be ·000007 linear for one degree Fahr.; and he argues that, as this amount would not account for the observed contraction in the crust, we must have recourse to some additional explanation, such as the escape of steam and vapours from volcanic orifices. The validity of the assertion that the amount of horizontal compression of the superficial strata is greater than the cooling of a solid earth can account for may be questioned. The violently contorted rocks indicative of great horizontal compression occur chiefly along the crests of the great terrestrial ridges where the maximum effects of corrugation were to be looked for. To the argument from climate it may be replied on the other hand, with great plausibility, that secular changes may be accounted for by the effect of the variations in the eccentricity of the earth's orbit combined with the precession of the equinoxes, as already described.

(6.) *Age of the Earth and Measures of Geological Time.*—The age of our planet is a problem which may be attacked either from the geological or physical side.

1. The geological argument rests chiefly upon the observed rates at which geological changes are being effected at the present time, and is open to the obvious preliminary objection that it assumes the existing rate of change as the measure of past revolutions,—an assumption which may be entirely erroneous, for the present may be a period when all geological events march forward more slowly than they used to do. The argument proceeds on data partly of a physical and partly of an organic kind. (*a*) The physical evidence is derived from such facts as the observed rates at which the surface of a country is being lowered by rain and streams, and new sedimentary deposits are formed. These facts will be more particularly dwelt upon in later portions of this article. If we assume that the land has been worn away, and that stratified deposits have been laid down nearly at the same rate as at present, then we must admit that the stratified portion of the crust of the earth must represent a very vast period of time. Dr Croll puts this period at not less, but possibly much more, than 60 million years. (*b*) On the other hand, human experience, so far as it goes, warrants the belief that changes in the organic world proceed with extreme slowness. Yet in the stratified rocks of the earth's crust we have abundant proof that the whole fauna and flora of the earth's surface have passed through numerous cycles of revolution,—species, genera, families, appearing and disappearing many times in succession. On any supposition it must be admitted that these vicissitudes in the organic world can only have been effected with the lapse of vast periods of time, though no reliable standard seems to be available whereby these periods are to be measured. The argument from geological evidence is strongly in favour of an interval of probably not much less than 100 million years since the earliest form of life appeared upon the earth, and the oldest stratified rocks began to be laid down.

[1] Sir W. Thomson, *Brit. Assoc. Rep.*, 1876, Sections, p. 5.
[2] Thomson, *Proc. Roy. Soc.*, April, 1862. [3] Thomson, *loc. cit.*
[4] Thomson, *Trans. Roy. Soc. Edin.*, xxiii. 157.
[5] Thomson, *Brit. Assoc. Rep.*, 1876, Sections. p. 7.
[6] *Proc. Roy. Soc.*, No. 188, 1878.
[7] This objection has been repeatedly urged by Sir William Thomson. See *Trans. Roy. Soc. Edin.*, xxiii. 157; and *Brit. Assoc. Rep.*, 1870, Sections, p. 7.
[8] See D. Forbes, *Geol. Mag.*, vol. iv. p. 435.

2. The argument from physics as to the age of our planet is based by Sir William Thomson upon three kinds of evidence:—(1) the internal heat and rate of cooling of the earth; (2) the tidal retardation of the earth's rotation; and (3) the origin and age of the sun's heat.

(1.) Sir William Thomson, applying Fourier's theory of thermal conductivity, pointed out some years ago (1862) that in the known rate of increase of temperature downward and beneath the surface, and the rate of loss of heat from the earth, we have a limit to the antiquity of the planet. He showed, from the data available at the time, that the superficial consolidation of the globe could not have occurred less than 20 million years ago, or the underground heat would have been greater than it is; nor more than 400 million years ago, otherwise the underground temperature would have shown no sensible increase downwards. He admitted that very wide limits were necessary. In more recently discussing the subject, he inclines rather towards the lower than the higher antiquity, but concludes that the limit, from a consideration of all the evidence, must be placed within some such period of past time as 100 millions of years.[1]

(2.) The argument from tidal retardation proceeds on the admitted fact that, owing to the friction of the tide-wave, the rotation of the earth is retarded, and is therefore much slower now than it must have been at one time. Sir William Thomson contends that had the globe become solid some ten thousand million years ago, or indeed any high antiquity beyond 100 million years, the centrifugal force due to the more rapid rotation must have given the planet a very much greater polar flattening than it actually possesses. He admits, however, that, though 100 million years ago that force must have been about 3 per cent. greater than now, yet "nothing we know regarding the figure of the earth and the disposition of land and water would justify us in saying that a body consolidated when there was more centrifugal force by 3 per cent. than now might not now be in all respects like the earth, so far as we know it at present."[2] Professor Tait, in repeating this argument, concludes that, taken in connexion with the previous one, "it probably reduces the possible period which can be allowed to geologists to something less than ten millions of years."[3] He does not state, however, on what grounds he so reduces the available period, nor does he notice the objection urged by Dr Croll that, granting the gradual submergence of the polar lands owing to the slackened speed of rotation, the subaerial denudation of the rising equatorial land might well keep pace with the effects of the oceanic subsidence, so that we cannot infer from the present form of the earth what may have been its precise amount of polar compression at the time of solidification.[4]

(3.) The third argument, based upon the age of the sun's heat, is confessedly less reliable than the two previous ones. It proceeds upon calculations as to the amount of heat which would be available by the falling together of masses from space, which gave rise by their impact to our sun. The vagueness of the data on which this argument rests may be inferred from the fact that in one passage Professor Tait places the limit of time during which the sun has been illuminating the earth as, "on the very highest computation, not more than about 15 or 20 millions of years," while, in another sentence of the same volume, he admits that, "by calculations in which there is no possibility of large error, this hypothesis [of the origin of the sun's heat by the falling together of masses of matter] is thoroughly competent to explain 100 millions of years solar radiation at the present rate, perhaps more."[5] One hundred millions of years is probably amply sufficient for all the requirements of geology.

III. Composition of the Earth's Crust.

MINERALS AND ROCKS.

The visible and accessible portion of the earth is formed of minerals and rocks. A mineral may be classified as an inorganic body distinguished by a more or less definite chemical composition, and usually a characteristic geometrical form. A rock is an aggregate mass, sometimes of one, more commonly of two or more minerals. Upwards of 800 species of minerals and a vast number of varieties have been described. A very large proportion of these occur but rarely, and, though interesting and important to the mineralogist, do not demand the special attention of the geologist. While almost every mineral may be made to yield data of more or less geological significance, only those which enter into the composition of rock masses, or which are of frequent occurrence as accessories there, require to be familiarly known by the student of geology.

1. Rock-Forming Minerals.

The following are the more important minerals which enter into the composition of rocks:—

Quartz (SiO_2) occurs either crystallized as rock-crystal, or non-crystalline as calcedony. In the former condition it is an essential constituent of granite, felsite, and many other igneous rocks, as well as of sandstone and numerous aqueous rocks. The non-crystallized or colloid quartz is chiefly met with in cavities and fissures of rock where it has been slowly deposited from aqueous solution. Numerous varieties of calcedony occur, as agate, carnelian, jasper, flint, chert, Lydian-stone, &c.

Felspars (silicates of alumina, with potash, soda, or lime) constitute the most abundant group of rock-forming minerals. For the purposes of the petrographer they are conveniently divided into two series—(1) the Monoclinic or Orthoclase felspars (with cleavage angles of 90°), containing from 4 to 16 per cent. of potash and

[1] *Trans. Roy. Soc. Edin.*, xxiii. 157; *Trans. Geol. Soc. Glasgow*, iii. 25.
[2] *Trans. Geol. Soc. Glasgow*, iii. 16.
[3] *Recent Advances in Physical Science*, p. 174.
[4] *Quart. Jour. Science*, July 1877.
[5] *Op. cit.*, pp. 153, 175.