409 feet.[1] More recently, in returning to this question, Dr Croll remarks "that the removal of two miles of ice from the Antarctic continent [and at present the mass of ice there is probably thicker than that] would displace the centre of gravity 190 feet, and the formation of a mass of ice equal to the one-half of this, on the Arctic regions, would carry the centre of gravity 95 feet farther, giving in all a total displacement of 285 feet, thus producing a rise of level at the north pole of 285 feet, and in the latitude of Edinburgh of 234 feet." A very considerable additional displacement would arise from the increment of water to the mass of the ocean by the melting of the ice. Supposing half of the two miles of Antarctic ice to be replaced by an ice-cap of similar extent and one mile thick in the northern hemisphere, the other half being melted into water and increasing the mass of the ocean, Dr Croll estimates that from this source an extra 200 feet of rise would take place in the general ocean level, so that there would be a rise of 485 feet at the north pole, and 434 feet in the latitude of Edinburgh.[2] There must thus have been an alternate submergence and emergence of the low polar lands due to the alternate shifting of the centre of gravity.

7. *Influence of the Earth's Movements upon Climate.*—Although the treatment of this subject involves a reference to questions which must be discussed in their proper place in subsequent parts of this article, it will be most appropriately inserted here as a distinct and most important branch of the astronomical relations of geology. In later pages it will be shown that the climate of the earth has undergone many great vicissitudes during geological history,—for example, that a warm and genial temperature has once prevailed in arctic latitudes, while at another time snow and ice extended far down into the heart of Europe. Of this latter change, which took place within a comparatively recent geological period, the traces still remain remarkably fresh, and have excited great interest and discussion. It is known as the Glacial Period or Ice Age. But we now know that other similar periods of great cold probably preceded it at widely separated intervals.

Various theories have been proposed in explanation of such striking variations in climate. Some of these have appealed to a change in the position of the earth's axis relatively to the mass of the planet (p. 216). Others have been based on the notion that the earth may have passed through hot and cold regions of space. Others, again, have called in the effects of terrestrial changes, such as the distribution of land and sea, on the assumption that elevation of land about the poles must cool the temperature of the globe, while elevation round the equator would raise it. But as the changes of temperature have affected vast areas of the earth's surface, while there is a total absence of all proof of any such enormous vicissitudes in physical geography as would be required, and since there is accumulating proof in favour of periodic alternations of climate, there is a growing conviction that no mere local changes could have sufficed, but that secular variations in climate must be assigned to some general and probably recurring cause.[3]

By degrees geologists accustomed themselves to the belief that the cold of the glacial period was not due to mere terrestrial changes, but was to be explained somehow as the result of cosmical causes. Among the various suggestions, one deserves careful consideration,—change in the eccentricity of the earth's orbit. Sir John Herschel[4] pointed out many years ago that the direct effect of a high condition of eccentricity is to produce an unusually cold winter followed by a correspondingly hot summer on the hemisphere whose winter occurs in aphelion, while an equable condition of climate will at the same time prevail on the opposite hemisphere. But both hemispheres must receive precisely the same amount of solar heat, because the deficiency of heat resulting from the sun's greater distance during one part of the year is exactly compensated by the greater length of that season. Sir John Herschel even considered that the direct effects of eccentricity must thus be nearly neutralized.[5] As a like verdict was afterwards given by Arago, Humboldt, and others, geologists were satisfied that no important change of climate could be attributed to change of eccentricity.

It is to the luminous memoirs of Dr James Croll that geology is indebted for the first fruitful suggestion in this matter, and for the subsequent elaborate development of the whole subject of the physical causes on which climate depends. He has been so good as to draw up for this article the following summary of his views (taken chiefly from his paper in the *Phil. Mag.* for February 1870). The reader will find the subject fully worked out in Dr Croll's work, *Climate and Time*, 1875.

"Assuming the mean distance of the sun to be 92,400,000 miles, then when the eccentricity is at its superior limit, ·07775, the distance of the sun from the earth, when the latter is in the aphelion of its orbit, is no less than 99,584,100 miles, and when in the perihelion it is only 85,215,900 miles. The earth is, therefore, 14,368,200 miles farther from the sun in the former than in the latter position. The direct heat of the sun being inversely as the square of the distance, it follows that the amount of heat received by the earth in these two positions will be as 19 to 26. The present eccentricity being ·0168, the earth's distance during our northern winter is 90,847,680 miles. Suppose now that, from the precession of the equinoxes, winter in our northern hemisphere should happen when the earth is in the aphelion of its orbit, at the time that the orbit is at its greatest eccentricity; the earth would then be 8,736,420 miles farther from the sun in winter than it is at present. The direct heat of the sun would therefore, during winter, be one-fifth less and during summer one-fifth greater than now. This enormous difference would necessarily affect the climate to a very great extent. Were the winters under these circumstances to occur when the earth was in the perihelion of its orbit, the earth would then be 14,368,200 miles nearer the sun in winter than in summer. In this case the difference between winter and summer in our latitudes would be almost annihilated. But as the winters in the one hemisphere correspond with the summers in the other, it follows that while the one hemisphere would be enduring the greatest extremes of summer heat and winter cold, the other would be enjoying perpetual summer.

"It is quite true that whatever may be the eccentricity of the earth's orbit, the two hemispheres must receive equal quantities of heat per annum; for proximity to the sun is exactly compensated by the effect of swifter motion. The total amount of heat received from the sun between the two equinoxes is therefore the same in both halves of the year, whatever the eccentricity of the earth's orbit may be. For example, whatever extra heat the southern hemisphere may at present receive per day from the sun during its summer months, owing to greater proximity to the sun, is exactly compensated by a corresponding loss arising from the shortness of the season; and, on the other hand, whatever deficiency of heat we in the northern hemisphere may at present have per day during our summer half-year, in consequence of the earth's distance from the sun, is also exactly compensated by a corresponding length of season.

"It is well known, however, that those simple changes in the sun's summer and winter distances would not alone produce a glacial epoch, and that physicists, confining their attention to the purely astronomical effects, were perfectly correct in affirming that no increase of eccentricity of the earth's orbit could account for that epoch. But the important fact was overlooked that, although the glacial epoch could not result directly from an increase of eccentricity, it might nevertheless do so indirectly from physical agents that were brought into operation as a result of an increase of eccentricity. The following is an outline of what these physical agents were, how they were brought into operation, and the way in which they may have led to the glacial epoch.

1 Croll, in *Reader* for 2d Sept. 1865, and *Phil. Mag.*, April 1866; Heath, *Phil. Mag.*, April 1869; Pratt, *Phil. Mag.*, March 1866; Fisher, *Reader*, 10th February 1866.

2 Croll, *Geol. Mag.*, new series, i. (1874), p. 347; *Climate and Time*, chaps. xxiii. and xxiv.

3 In Lyell's *Principles of Geology* the doctrine of the influence of geographical changes is maintained.

4 *Trans. Geol. Soc.*, vol. iii. p. 293 (2d series).

5 *Cabinet Cyclopædia*, sec. 315; *Outlines of Astronomy*, sec. 368.

"With the eccentricity at its superior limit and the winter occurring in the aphelion, the earth would, as we have seen, be 8,736,420 miles farther from the sun during that season than at present. The reduction in the amount of heat received from the sun, owing to his increased distance, would lower the midwinter temperature to an enormous extent. In temperate regions the greater portion of the moisture of the air is at present precipitated in the form of rain, and the very small portion which falls as snow disappears in the course of a few weeks at most. But in the circumstances under consideration, the mean winter temperature would be lowered so much below the freezing-point that what now falls as rain during that season would then fall as snow. This is not all; the winters would then not only be colder than now, but they would also be much longer. At present the winters are nearly eight days shorter than the summers; but with the eccentricity at its superior limit and the winter solstice in aphelion, the length of the winters would exceed that of the summers by no fewer than thirty-six days. The lowering of the temperature and the lengthening of the winter would both tend to the same effect, viz., to increase the amount of snow accumulated during the winter; for, other things being equal, the larger the snow-accumulating period the greater the accumulation. It may be remarked, however, that the absolute quantity of heat received during winter is not affected by the decrease in the sun's heat,[1] for the additional length of the season compensates for this decrease. As regards the absolute amount of heat received, increase of the sun's distance and lengthening of the winter are compensatory, but not so in regard to the amount of snow accumulated. The consequence of this state of things would be that, at the commencement of the short summer, the ground would be covered with the winter's accumulation of snow. Again, the presence of so much snow would lower the summer temperature, and prevent to a great extent the melting of the snow.

"There are three separate ways whereby accumulated masses of snow and ice tend to lower the summer temperature, viz.:—

"*First*, By means of direct radiation. No matter what the intensity of the sun's rays may be, the temperature of snow and ice can never rise above 32°. Hence the presence of snow and ice tends by direct radiation to lower the temperature of all surrounding bodies to 32°. In Greenland, a country covered with snow and ice, the pitch has been seen to melt on the side of a ship exposed to the direct rays of the sun, while at the same time the surrounding air was far below the freezing-point; a thermometer exposed to the direct radiation of the sun has been observed to stand above 100°, while the air surrounding the instrument was actually 12° below the freezing-point. A similar experience has been recorded by travellers on the snow-fields of the Alps. These results, surprising as they no doubt appear, are what we ought to expect under the circumstances. Perfectly dry air seems to be nearly incapable of absorbing radiant heat. The entire radiation passes through it almost without any sensible absorption. Consequently the pitch on the side of the ship may be melted or the bulb of the thermometer raised to a high temperature by the direct rays of the sun, while the surrounding air remains intensely cold. The air is cooled by *contact* with the snow-covered ground, but is not heated by the radiation from the sun.

"When the air is charged with aqueous vapour, a similar cooling effect also takes place, but in a slightly different way. Air charged with aqueous vapour is a good absorber of radiant heat, but it can only absorb those rays which agree with it in *period*. It so happens that rays from snow and ice are, of all others, those which it absorbs best. The humid air will absorb the total radiation from the snow and ice, but it will allow the greater part of, if not nearly all, the sun's rays to pass unabsorbed. But during the day, when the sun is shining, the radiation from the snow and ice to the air is negative; that is, the snow and ice cool the air by radiation. The result is, the air is cooled by radiation from the snow and ice (or rather, we should say, *to* the snow and ice) more rapidly than it is heated by the sun; and, as a consequence, in a country like Greenland, covered with an icy mantle, the temperature of the air, even during summer, seldom rises above the freezing-point. Snow is a good reflector, but as simple reflection does not change the character of the rays they would not be absorbed by the air, but would pass into stellar space. Were it not for the ice, the summers of North Greenland, owing to the continuance of the sun above the horizon, would be as warm as those of England; but, instead of this, the Greenland summers are colder than our winters. Cover India with an ice sheet, and its summers would be colder than those of England.

"*Second*, Another cause of the cooling effect is that the rays which fall on snow and ice are to a great extent reflected back into space. But those that are not reflected, but absorbed, do not raise the temperature, for they disappear in the mechanical work of melting the ice. For whatsoever may be the intensity of the sun's heat the surface of the ground will be kept at 32° so long as the snow and ice remain unmelted.

"*Third*, Snow and ice lower the temperature by chilling the air and condensing the vapour into thick fogs. The great strength of the sun's rays during summer, due to his nearness at that season, would, in the first place, tend to produce an increased amount of evaporation. But the presence of snow-clad mountains and an icy sea would chill the atmosphere and condense the vapour into thick fogs. The thick fogs and cloudy sky would effectually prevent the sun's rays from reaching the earth, and the snow, in consequence, would remain unmelted during the entire summer. In fact, we have this very condition of things exemplified in some of the islands of the Southern Ocean at the present day. Sandwich Land, which is in the same parallel of latitude as the north of Scotland, is covered with ice and snow the entire summer; and in the island of South Georgia, which is in the same parallel as the centre of England, the perpetual snow descends to the very sea-beach. Captain Sir James Ross found the perpetual snow at the sea-level at Admiralty Inlet, South Shetland, in lat. 64°; and while near this place the thermometer in the very middle of summer fell at night to 23° F. The reduction of the sun's heat and lengthening of the winter, which would take place when the eccentricity is near to its superior limit and the winter in aphelion, would in this country produce a state of things perhaps as bad as, if not worse than, that which at present exists in South Georgia and South Shetland.

"The cause which above all others must tend to produce great changes of climate, is the deflexion of great ocean currents. A high condition of eccentricity tends, we have seen, to produce an accumulation of snow and ice on the hemisphere whose winters occur in aphelion. The accumulation of snow in turn tends to lower the summer temperature, cut off the sun's rays, and retard the melting of the snow. In short, it tends to produce on that hemisphere a state of glaciation. Exactly opposite effects take place on the other hemisphere, which has its winter in perihelion. There the shortness of the winters, combined with the high temperature arising from the nearness of the sun, tends to prevent the accumulation of snow. The general result is that the one hemisphere is cooled and the other heated. This state of things now brings into play the agencies which lead to the deflexion of the Gulf-stream and other great ocean currents.

"Owing to the great difference between the temperature of the equator and the poles, there is a constant flow of air from the poles to the equator. It is to this that the trade-winds owe their existence. Now, as the strength of these winds will, as a general rule, depend upon the difference of temperature that may exist between the equator and higher latitudes, it follows that the trades on the cold hemisphere will be stronger than those on the warm. When the polar and temperate regions of the one hemisphere are covered to a large extent with snow and ice, the air, as we have just seen, is kept almost at the freezing-point during both summer and winter. The trades on that hemisphere will, of necessity, be exceedingly powerful; while on the other hemisphere, where there is comparatively little snow or ice, and the air is warm, the trades will consequently be weak. Suppose now the northern hemisphere to be the cold one. The north-east trade winds of this hemisphere will far exceed in strength the south-east trade winds of the southern hemisphere. The *median line* between the trades will consequently lie to a very considerable distance to the south of the equator. We have a good example of this at the present day. The difference of temperature between the two hemispheres at present is but trifling to what it would be in the case under consideration; yet we find that the south-east trades of the Atlantic blow with greater force than the north-east trades, sometimes extending to 10° or 15° N. lat., whereas the north-east trades seldom blow south of the equator. The effect of the northern trades blowing across the equator to a great distance will be to impel the warm water of the tropics over into the Southern Ocean. But this is not all; not only would the median line of the trades be shifted southwards, but the great equatorial currents of the globe would also be shifted southwards.

"Let us now consider how this would affect the Gulf-stream. The South American continent is shaped somewhat in the form of a triangle, with one of its angular corners, called Cape St Roque, pointing eastwards. The equatorial current of the Atlantic impinges against this corner; but as the greater portion of the current lies a little to the north of the corner, it flows westwards into the Gulf of Mexico and forms the Gulf-stream. A considerable portion of the water, however, strikes the land to the south of the cape, and is deflected along the shore of Brazil into the Southern Ocean, forming what is known as the Brazilian current. Now, it is obvious that the shifting of the equatorial current of the Atlantic only a few degrees to the south of its present position—a thing which would certainly take place under the conditions which we have been detailing—would turn the entire current into the Brazilian branch, and instead of flowing chiefly into the Gulf of Mexico, as at present, it would all flow into the Southern Ocean, and the Gulf-stream would consequently be stopped. The stoppage of the Gulf-stream, combined

1 When the eccentricity is at its superior limit, the absolute quantity of heat received by the earth during the year is, however, about one three-hundredth part greater than at present. But this does not affect the question at issue.

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."

[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.

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

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.