ART. IV.—*On the Unity of Geological Phenomena in the Solar System;* by L. SÆMANN.

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THE observations upon the solar eclipse of July 18, 1860, have given rise among astronomers and physicists to some interesting discussions upon the nature of the sun, which seem to merit the attention of geologists. The opinion hitherto generally adopted is founded upon the view suggested by Arago from his observations concerning the spots upon the sun. This great as-

* Proc. American Academy (1861), v. p. 192.

tronomer conceived that by admitting a dark nucleus surrounded by a luminous atmosphere or photosphere, it would be easy to explain the luminous phenomena presented by the sun.* On the other hand Leverrier from the observations made in Algiers by the scientific commission from the Paris Observatory maintains that the sun is luminous from the incandescence of its nucleus, and that the variations in the intensity of the light at its surface may be explained by atmospheric perturbations similar to those of our own atmosphere. Mr. Leverrier is led to admit for the sun, at least two atmospheres different in nature and in density, and it is principally with regard to the external envelope, or rose-colored atmosphere, which gives rise to the flames or luminous protuberances, that there exists a difference of opinion among observers.

Other observations of a very different nature give a strong support to the conclusions of Leverrier; the remarkable discoveries of Kirchhoff and Bunsen upon the dark lines in the solar spectrum, have enabled us to submit the solar atmosphere to an optical analysis which makes known its chemical composition, and shows it to contain several alkali-metals, including sodium and calcium, which can only exist there in the state of gas or vapor. The discussion of this interesting subject belongs especially to chemists and physicists, but geologists may be permitted to express their sympathy for that view which accords the best with the theory that forms the basis of their science, and is, moreover, entitled to a certain authority among mathematicians and astronomers, inasmuch as it bears the name of the illustrious Laplace.

All modern geological theories implicitly admit the unity of our planetary system, in so far as that they suppose the sun, the planets and their satellites, to have been formed from one primitive substance; their very variable densities only show that the constituent elements are grouped in varying proportions.† It is not necessary to suppose that each body of the system presents exactly the same chemical combinations as are known on our globe, for affinities will vary with the temperature and the densities of the elements, but we may admit that a portion of any one of these celestial bodies brought to the surface of our earth and there subjected to terrestrial influences, would in obedience to the chemical affinities which here prevail, be at length converted into *a portion of earth.*

This unity of origin once admitted there is no longer any reason for denying the analogy if not the identity, of the phe-

[* This view of the constitution of the sun, so ingeniously defended by Arago, (see *Annuaire du Bureau des Longitudes* for 1842, p. 510,) is by him there called the theory of William Herschel, who appears to have first clearly defined it.—*Translator.*]

† [Or in different degrees of condensation.—*Translator.*]

nomena which have accompanied the formation of the sun and the planets, at least of those whose density approaches the nearest to that of the earth. All of them must have passed by cooling from a state of igneous fluidity to a solid condition, and their present state will depend upon the greater or less facility which their volume and their composition will have offered to the passage of heat. The chemical composition being the same, the duration of the geological epochs upon each planet will have been nearly in a direct ratio to its volume, setting aside certain corrections of which it is not necessary at present to discuss the elements. The low density of the sun, which is little greater than that of water (0·252 that of the earth,) would lead us to suppose the existence there of a peculiar condition of things; science has, however, as yet no means of appreciating the action of a heat so excessive as that which is required to maintain the alkali-metals in a gaseous state, and it appears possible that if the temperature of the sun were reduced to that of the earth its density would also be approximated to that of our planet. However this may be, the analogies of Leverrier's theory with the observations of geologists are too important as showing the connection between the two great branches of natural science, not to encourage geologists to further inquiry in the same direction, and it is with this object in view that we have been led to the following reflections.

We admit a similar geological (or chemical) constitution for the various bodies of the solar system, and from this conclude that the phenomena which have accompanied their formation and their successive transformations, must have been similar. Thus the planets and satellites whose density is near to that of our earth may be supposed to have passed through the different stages of liquid and solid incandescence, of the successive liquefaction of portions of their gaseous envelopes, and to have finally been the seat of an organic creation.

Of these planetary bodies the best known to us is the moon, and we shall now inquire to what extent our slight knowledge of it is in accordance with the observations made on our earth, and with the present state of the sun as supposed by Mr. Leverrier. It is well known that astronomers, so soon as they became possessed of good telescopes, discovered mountains and plains (or seas) on the surface of the moon, and the immediate application of these names shews the great resemblance which was supposed to exist between the surfaces of the moon and the earth. It does not appear surprising that the form of the lunar mountains should be met with among only a small number of those on our planet, and physicists easily explain the greater elevation and the steep declivities of the former by the comparatively feeble action of the centripetal force at the moon's surface. But one of the gravest objections to the idea of a common origin of the moon and the earth is the apparent absence of water and air from the surface of our satellite, thus seriously embarrassing those geologists who attribute terrestrial volcanic phenomena to the intervention of these expansible elements.

If however we admit for the earth and the moon an identical and simultaneous point of departure we can understand that their cooling has taken place at a rate nearly proportioned to their volume. That of the moon being about two hundreths the volume of the earth, its temperature, if we admit an equal conductibility, will have decreased with a rapidity fifty times greater, so that the geological epochs of the moon will have been in the same proportion shorter than the corresponding epochs on the earth, up to the time when the solar heat began to be an appreciable element. The moon has then advanced much more rapidly than the earth in the series of phenomena through which both must pass, and we may therefore logically suppose that our globe will one day offer the same general characters as are now presented by the moon.

We believe then that the water which covers the surface of the earth and the air which surrounds it will one day disappear, as a necessary consequence of the complete cooling of the interior of our planet. Rocks, with few exceptions, readily absorb moisture, and the more crystalline varieties are the most porous; we need not, however, consider the quantity of water which rocks may imbibe in this way, for the total amount of this element on the earth's surface is so small when compared with the whole mass of the globe, that the ordinary processes of chemical analysis would not detect its presence. If we take the mean depth of the ocean at 600 meters* (=1968 feet), its weight will be equal to one twenty-four-thousandth of the earth, which being reduced to decimals, would give for 100 parts,

Earth,	99·9958
Water,	·0042

In the Bulletin of the Geol. Society of France, (2d series, vol. x, p. 131,) Durocher has published a series of experiments made to determine the quantity of water in those minerals which enter into the structure of rocks, such as the feldspars, micas, hornblende and pyroxene, and which are regarded as anhydrous in composition. These minerals were reduced to coarse powder and exposed to moist air, the proportion of water being determined both before and after; it will be sufficient for our purpose to give the amount of water found after exposure. The orthoclase of Utoë absorbed in this way 0·41 for 100 parts, while the mean

* This depth is deduced from the comparison of the relative areas of land and water which are taken as 1:3, the elevation and depression of the surface being assumed as proportional to the square roots of their surfaces. (Saigey, *Physique du Globe*, 232.) The depth of the Pacific Ocean as deduced by Bache from the earthquake wave of Dec. 1854, was about 13,000 feet.—(This Jour. [2], xxx, 83.)—Eds.

of seven other varieties of the same species was 1·28, and that of thirty specimens of various substances 1·27. We have already seen that if the whole of the ocean were to be equally distributed throughout the earth this would contain only 0·0042, or 100 times less than the least hygrometric of the feldspars. It is probable that the water of the ocean thus absorbed would enter into chemical combination; at all events it would occupy a space much less than the pores produced by the shrinking of the rocks.

If, now, we attempt a similar calculation for the atmosphere, we find that in supposing a height of eight kilometers, the total volume of the air which surrounds our globe, brought to the density which it has at the surface, would be about four millions of cubic myriameters, the volume of the earth being equal to 1083 millions, or 270 times that of the air, so that a contraction of the primitive volume producing a vacuum of four thousandths ($\frac{1}{250}$) would be more than sufficient to absorb the whole of the atmosphere. (In calculating the volume of the atmosphere we have multiplied the surface of the globe in square myriameters, by 0·8, which gives a sufficiently accurate result, the more so that the density of the air in the interior of the earth will be everywhere greater than at the surface.)

It now remains to be seen whether the assumption of a shrinking of four thousandths can be justified by analogies. In the want of direct determinations of the porosity of crystalline rocks, upon which subject I am not aware of any published experiments, the observations upon the fusion of rocks, and the determinations of their densities in the crystalline and vitreous states admit of an indirect application to the question before us. The experiments of Charles Ste. Claire Deville in the *Comptes Rendus* for 1845, and of Delesse in the *Bulletin* for 1847, agree so closely in this matter that we give them the preference over those of Bischoff, published in 1842. Deville and Delesse found that the fusion of rocks yields glasses whose density is generally inferior to that of the rock in the crystalline state. This diminution for granite is equal to from nine to eleven hundreths, and it is evident that such a glass passing to a crystalline state and retaining its volume must present vacant spaces in direct proportion to the augmentation of density, that is to say, equal to about one-tenth of its volume. If we take the mean density of granite at 2·60, it might with such a degree of porosity imbibe 3·9 parts in 100·0 of its weight of water. This shrinking of one-tenth is no exaggeration, and such a rock would still be a good building material, although containing twenty-five times more vacant space than our calculation requires.

The vitreous state of a body is nothing more than a fixing of its molecules in the positions which belong to them in the liquid state, and probably represents the liquid in its greatest degree of density. The crystallization of barley sugar, of wrought iron, and of Reaumur's porcelain, are striking examples of the tendency of molecules to group themselves in crystals even in the midst of solid masses, and we can thus readily understand the absence of vitreous substances among the older crystalline rocks. The great difficulty is to determine with exactness the proportion of the vacant spaces resulting from this change, since these will vary for each body, and probably also with the volume of the mass. Sulphur fused in an open vessel crystallizes slowly, the level of the liquid sinks a little, and after complete solidification the surface is covered with hollows resulting from the shrinking, whereas if cooled in a spherical shape these cavities would naturally be formed at the centre. Water and bismuth as is well known, behave in a very different and remarkable manner, the first dilating eight or ten hundredths at the moment of congelation, and the second one fifty-third. The only conclusion to be drawn from these facts is that each body in solidification behaves in a different manner, and that for the solution of the question before us, we can only take into account the well known porosity of rocks. The problem, however, appears to me one of great importance in connection with theoretical geology; if we admit with Deville that at the moment of crystallization, the density of rocks is in all cases augmented, we are forced to conclude that all the crystalline masses formed at the surface of the liquid globe must have sunk and accumulated at the centre. The effect of a similar action has been shown by physicists, who have demonstrated that the cold of winter would freeze our lakes and rivers from the bottom if the ice sunk at the moment of its formation, as would the solidified parts of a lake of molten sulphur. We should then have in place of a liquid globe surrounded by a solid shell, a mass solidified to the centre, a conclusion which is perhaps more in harmony with the feeble and local action which the interior is known to exert on the surface. Since then the data are wanting to fix the amount of shrinking in the crystallization of rocks, we may find in an analogous phenomenon some terms of comparison. The difference between the density of cast metals, and the same after hammering, can only arise from a contraction similar to that which takes place in igneous rocks. The surface becoming solid while the interior is yet liquid, the natural contraction of this portion is prevented, and from this necessarily result vacant spaces in the mass, which are afterwards compressed by the action of the hammer. In calculating from the differences in density the volume of the vacant spaces thus produced, we find for iron a contraction of 0·075, for nickel 0·045; for aluminum 0·041; for copper 0·011; for gold 0·005, while the contraction of the earth necessary to absorb the whole atmosphere, would be only 0·004. From this it results that an ingot of gold, the most solid obtained by the fusion of a metal, contains more vacant space in proportion to its volume than would be required in the globe for the absorption of its gaseous envelope; it is scarcely possible that any crystalline rock should be wanting in this slight degree of porosity.

From the preceding considerations, the successive absorption of the air and water by the solid portions of the globe becomes in the highest degree probable, and we may conclude that our earth will one day present that same total absence of ocean and atmosphere which we now remark in the moon. It is evident that this progress of the waters towards the earth's centre must have long been in operation, and it becomes interesting to consider the effect which this must have had upon the level of the ocean. Let us suppose that the rocks near to the surface of the earth contain one hundredth of water, a proportion which from the above calculation will not be regarded as excessive, and that the water moreover does not exist in this proportion at a depth beyond that at which the terrestrial heat equals 100 degrees centigrade. If we take the augmentation of heat in descending to be one degree for thirty-three meters this will give a depth of about 3000 meters, while one part of water by weight in one hundred parts of a rock whose density is equal to 2·5, will correspond to a volume of one-fortieth. We shall now calculate the volume of this external layer which we have supposed to be thus impregnated with water, regarding it as a prism having for its base the surface of the earth, with a height of 3000 meters, which would give a mass of 1,530,000 cubic myriameters, containing 38,000 cubic myriameters of water. The total volume of the ocean being one forty-eighth thousandth that of the globe, or 225,000 cubic myriameters, it follows that this layer of 3000 meters of earth would contain a volume of water equal to one-sixth of the present ocean. Whatever may be the real value of these figures which we have adopted to render the demonstration more clear, the interest and importance of this inquiry is evident.

I am convinced that the ultimate complete cooling of the interior of the earth is inevitable. We may affirm on general principles that between two media of different temperatures separated by a layer of rock which is a conducter of heat, an equilibrium will at length be established. It is probable that this cooling is however to a great extent, effected by the innumerable currents of water and gases which circulate in every direction through the interior of the globe, and of which volcanic eruptions, hot springs and *suffioni* are only the more violent manifestations attaining the earth's surface. The recent ingenious experiment of Daubrée has shown us that water may be drawn by capillary force towards spaces heated much above its boiling point. The water thus conveyed, in passing into the state of vapor does not everywhere produce volcanic phenomena, for these probably require the concurrence of conditions which are not often found. The aqueous vapor will ordinarily ascend to colder portions of the earth's crust and there yielding its heat to the walls of the fissures will flow back in the liquid state to the source of heat to repeat the same process, while on the other hand currents of cold water will absorb the heat thus conveyed to the rocks and bring it to the surface by thermal springs.

The general permeability of rocks is so well admitted by most geologists that I have not thought it necessary to seek for proof of it in the discussions of the present question; the brilliant conception of the metamorphism of rocks by the humid way, which has been so well maintained by the ablest chemists, is only possible on this condition. The permeability of rocks also explains in a satisfactory manner the formation of agates, and of zeolites, arragonite and other minerals in the midst of the most compact basalts, and of geodes of quartz in the Norwegian granites. We may also recall the artificial colors which are given to agates. Mr. Damour has even shown by a series of curious experiments that the water which is ordinarily considered as chemically combined in certain hydrated silicates, such as zeolites, may be in part extracted from them, and again restored without any apparent alteration in these minerals.