have not each taken precisely the same view of the process by which the result ensues; but whatever the precise process may be, the chemical theory, if true, removes the objection made by Croll to Hæckel's contention as to the immensity of time, which the phenomena of Evolution show must have elapsed since the dawn of life upon the earth.¹

IV.—ON ACCUMULATION AND DENUDATION, AND THEIR INFLUENCE IN CAUSING OSCILLATION OF THE EARTH'S CRUST.

By CHARLES RICKETTS, M.D., F.G.S.

NO fact in Physical Geology is more frequently recorded than a simultaneous occurrence of subsidence of the earth's crust where deposition of sedimentary strata has been in progress. Reference is often made to the fact that the basement beds of different sedimentary formations were deposited in shallow water, and to the indications presented by subsequent deposits that they were accumulated in a sea of moderate depth. On them immense accumulations may have been deposited in successive strata, amounting even to miles in thickness; showing that with the deposition there has been a corresponding depression of the original surface. Though these phenomena are so inseparable in their occurrence and so well known, English geologists, until the last few months, have made little, it may even be said no endeavour, to determine whether they should be associated as cause and effect. This has not been the case with American geologists.

In 1859 Professor James Hall of the United States determined that "the removal of large quantities of sediment from one part of the earth's crust, and its transportation and deposition in another, would produce oscillation of level. When these are spread along a belt of sea-bottom, the first effect of this great augmentation of matter would be to produce a yielding of the earth's crust beneath, and a gradual subsidence would be the consequence." He founded this opinion on the results of an examination of Palæozoic strata along the Appalachian chain, of which strata the Carboniferous formation alone reaches to a thickness of 14,000 feet. It is evident "that the depth of the sea was not originally so great as the thickness of these accumulations, and the occurrence of ripple marks, marine plants, and other conditions prove that the sea in which these deposits were made was at all times shallow or of moderate depth."²

In North America it is so generally accepted that the phenomena

¹ The following are Croll's words: "Prof. Hæckel may make any assumption he chooses about the age of the sun, but he must not do so in regard to the sun's heat. One who believes it inconceivable that matter can be created or annihilated may be allowed to maintain that the sun existed from all eternity, but he cannot be permitted to assume that our luminary has been losing heat from all eternity."—"Nature" for Jan. 10, 1878.

² Palæontology of New York, vol. iii., Introduction. An account of Professor Hall's opinions is given in Chemical and Geological Essays, Essay V., by T. Sterry Hunt, LL.D., F.R.S.

of subsidence and accumulation are dependent the one upon the other, that Captain C. E. Dutton of the United States Ordnance Survey considers that "few geologists question that great masses of sedimentary matter displace the earth beneath them and subside."¹ This statement by Dutton cannot refer to geologists on this side of the Atlantic, by whom, it may be said, the subject has hardly been taken into consideration.

Sir John Herschel, in a letter to (Sir) Charles Lyell, dated 1836, made slight allusions to the effect which "the transfer of pressure from one part of the earth's surface to another would have on the fluid or semi-fluid matter beneath the outer crust." He supposed that "if the whole floated on a sea of lava, there would merely be an almost infinitely minute flexure of the strata."² He subsequently (in 1859) showed that "the bed of an ocean supported on a yielding substratum may be depressed, without a corresponding depression of its surface, by the simple laying on of material;"³ and in a popular lecture illustrated the consequences resulting from the increase of pressure in one place and relief in others by what would occur to a ship floating even on her keel. "If the weight on the starboard be transferred to the port side, she will heel over to port; so if the continents be lightened, they will rise; if the bed of the sea receives additional weight, it will sink."⁴ The theory did not receive such attention as was due to the great authority from whom it emanated; perhaps because the illustrations advanced did not afford sufficient or conclusive proof.

In the Geological Record for 1877 (p. 173) a French geologist is stated to regard the increasing weight of deposits in areas of subsidence as the chief factor of geological change.⁵

Besides these authors, no one having authority such as would influence geological opinion has, until within the last few months, considered the subject, though the records of the simultaneous occurrence of accumulation and subsidence are almost innumerable. Those who have watched the progress of geology must with Darwin "have been surprised to note how author after author, in treating of this or that great formation, has come to the conclusion that it was accumulated during subsidence;"⁶ and it appears to me equally as great a wonder that so little endeavour has been made by these authors to determine whether the two classes of phenomena should be associated as cause and effect.

Mr. J. Starkie Gardner, F.G.S., in the GEOLOGICAL MAGAZINE for June, 1881,⁷ and the Rev. Osmond Fisher, F.G.S., in his book

¹ The Geological History of the Colorado River and Plateaus, *Nature*, vol. xix. 1879, p. 251.

² Proceedings of the Geological Society, vol. ii. p. 548.

³ Physical Geography, by Sir John F. W. Herschel, Bart., F.R.S., etc., § 132.

⁴ About Volcanos and Earthquakes, Familiar Lectures, Lecture I. p. 11.

⁵ V. H. Hermite, Sur l'unité des forces en Géologie, *Compt. Rend.* t. lxxiv. pp. 459-461, 510-512.

⁶ On the Origin of Species, by Charles Darwin, F.R.S., chap. ix., third edition, p. 313.

⁷ Subsidence and Elevation, and on the Permanence of Continents, *GEOL. MAG.* Dec. II. Vol. VIII. p. 241.

entitled "Physics of the Earth's Crust," 1881, have commented on the occurrence of subsidence during the deposition of the different geological formations; and also where accumulations are in progress at the present time under the sea; or on land covered with a heavy load of snow, as in Greenland. They agree with me in considering the depression as the result of and caused by the weight of the accumulations. (I must express how greatly I feel indebted to these authors for the courtesy with which they have recognized such deductions made by myself as far back as 1865,¹ and more especially at various periods since 1871.²) They agree with me in considering the depression as the result of and caused by the weight of the accumulations. Mr. Fisher considers "it requisite for the explanation of the phenomena that there be a liquid, or at least a plastic substratum for the crust to rest on; nor is it easy to explain the sinking of areas in proportion to their becoming over-loaded with sediment upon any other supposition; but if such a liquid substratum be granted, many of the facts are more easily explained. If the present configuration of the Himalayan region be one of approximate equilibrium, if much sediment be brought off the mountains and spread over the plains, the mountains must become after a while too light and the plains too heavy; and accordingly the mountains rise and the plains sink to restore the contour"³ (or equipoise).

It is now almost universally acknowledged that valleys have been excavated by subaerial agencies, and that the materials which once filled up the vacancies have been removed by rain and rivers, and carried down and deposited near the mouths of their respective rivers and neighbouring parts of the sea. Towards the mouths of large rivers every one knows the bottoms of the valleys are filled with detritus brought down by the stream; these deltoid accumulations being often not only of great width, but also of very considerable thickness. According to Sir Charles Lyell,⁴ the thickness has been proved by borings to be more than 630 feet in the case of the Mississippi; but he considers it probable that it may have attained to twice or thrice that thickness; in the case of the Ganges, the depth reached was 481 feet; and in the Po 400 feet; each example afford-

¹ A Ramble in Shropshire, Proc. Birkenhead Lit. and Scient. Soc. 1865; A Wooden Implement found in Bidston Moss, Proc. Liverpool Geol. Soc. 1865-66.

² President's Address, by Charles Ricketts, Proc. Liverpool Geol. Soc., Session 1871-72. Also an abstract of the same, entitled "On Subsidence as the Effect of Accumulation," GEOL. MAG. Vol. IX. p. 119, etc.

³ Physics of the Earth's Crust by the Rev. Osmond Fisher, M.A., F.G.S., p. 83. Referring to the Himalayan region, it was stated by myself in 1875, when replying to objections which had been raised, that the removal by denudation of those portions of the mass which once filled up the spaces now forming the valleys and passes of this great mountain range, must have diminished proportionately the amount of weight pressing upon the fluid substratum. Should the sediment brought thence by the Ganges and Brahmapootra, and deposited in the Bay of Bengal, cause subsidence by its weight, it follows that the area from which the sediment has been derived must rise in proportion to the amount of material removed.—The Cause of the Glacial Period, by Charles Ricketts, GEOL. MAG. Dec. II. Vol. II. p. 574, foot-note.

⁴ Principles of Geology, vol. i. chapters 18 and 19.

ing indications of ancient land surfaces now situated at great depths. It is more than probable that the amount of deposits, so far as it has been proved by borings, represents but a moderate proportion of their entire thickness.

Beyond the alluvial plains or deltas, estuaries or bays are very generally formed, being the extensions or prolongations of depressed valleys, into which sea-water enters. Rivers bring down an amount of debris immensely greater than can be disposed of by their overflow during floods upon deltoid plains. The amount removed, as indicated by the spaces left between the flanks of valleys, and carried into the sea, would, if there were no subsidence, form very extensive plains where there is now sea, and would extend in some cases to hundreds, it may be even to thousands of miles beyond the present deltas; whereas, notwithstanding the great accumulations, deltas are by subsidence transformed into bays, and instead of shallow water the sea becomes, at a few miles from the mouth of the river, unfathomable by the ordinary deep-sea line. Lyell has directed attention to the rapid increase of depth, from shallow water at the mouth of the Mississippi, to 95 fathoms at a distance of 12 miles; 144 fathoms at 20 miles; and 452 fathoms at 52 miles.¹

The inference to be drawn from the occurrence of subsidence near the mouths, of great rivers appears to be, that where there is the greatest amount of accumulation, there subsidence has occurred to the greatest extent, progressing more rapidly than the filling up of the areas by sedimentary deposits.

It is a remarkable coincidence that subsidence of land, when covered with heavy accumulations of perennial snow, should be a phenomenon of general occurrence; it prevailed in the northern hemisphere during former periods over immense districts, but is restricted to a limited area (Greenland) at the present time. All writers on glacial geology recognize this progressive submersion of the land during what is called the 'Glacial Period,' when extensive districts both in Europe and North America, now fertile and luxuriant, were buried under a thick covering of snow; and the bays and seas in their vicinity were packed with icebergs and floating ice; also that a partial re-elevation occurred at its termination. This subsidence may be chiefly ascribed to the weight of the snow heaped upon the land, and in part to the clay which, in muddy streams, issued from beneath the glaciers, and was deposited in a sea covered with bergs and pack-ice bearing rock fragments, which they had carried from many distant localities. The melting of the floating ice caused these erratic pebbles, etc., to be dropped into this clay, and thus become an integral portion of the Boulder-clay. The combined pressure of the snow upon the ground, and the Boulder-clay upon the bed of the sea, weighed down the crust of the earth. It was again raised to a considerable extent upon the return of a more genial climate, which relieved the land of its load of ice and snow.²

¹ Principles, vol. i. chap. xix.

² President's Address, by Charles Ricketts, Proc. Liverpool Geol. Soc. Session 1871-72; also an abstract of the same, GEOL. MAG. Vol. IX. 1872, p. 119.

It appears that Mr. T. F. Jamieson, in 1865, was the first who attributed this depression in different countries during the Glacial period "to the enormous weight of ice thrown upon the land; and considered that the melting of the ice would account for the rising of the land which seems to have followed the decrease of the glaciers."¹

Professor Shaler, of Harvard College, U. S. A., in 1874, also appears to have arrived independently at the same conclusions respecting the cause of subsidence during the Glacial period; he considers that "we may more reasonably look to the weight of ice accumulated on the continents for the depression of the land areas it occupied than to any other cause."²

Similar explanations, in which Mr. Fisher coincides, may account for the subsidence recently occurring in Greenland simultaneously with a rapid increase of accumulated snow; and also for the gradual rise of Scandinavia as a natural result of the recession of glaciers.

In all the older rocks the same fact is evident:—wherever any large amount of strata has been laid down, there has likewise been a persistent depression, which progressed in at least an equal degree with the accumulation. In each individual formation, throughout the whole series, from the Laurentian rocks of Canada, or the Longmynd rocks of Shropshire, up to those now in process of deposition, the record in the one is the record in them all,—*it was formed during a period of subsidence.*

Though there has thus occurred a simultaneous and progressive depression during the deposition of the accumulations constituting stratified rocks, it might be argued that the subsidence has taken place to the same extent over the whole area, and that the strata are thicker in one place than in another simply because their bases have been deposited on surfaces of unequal elevation, that is, on areas consisting of submerged valleys and hills. It requires a certain stratum, forming as it were a base-area, traceable over extensive districts, and situated, when formed at or about the same level, before the relative amount of subsequent deposition and subsidence can be calculated in different portions of the district in question. The Carboniferous formation affords most satisfactory examples for determining the problem.

(To be continued in our next Number.)

V.—ON THE BRECCIATED BED IN THE DIMETIAN AT ST. DAVIDS.

By THOS. M'KENNY HUGHES, M.A.,

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IN recent discussions upon the classification of the Archæan, great importance has naturally been attached to the occurrence of beds of fragmental origin. In the distinctly volcanic beds these are numerous; in the older or more highly metamorphosed portion of

¹ History of the last Geological changes in Scotland, by Thomas F. Jamieson, F.G.S., Quart. Journ. Geol. Soc. vol. xxi. p. 178.

² Recent Changes on the Coast of Maine, by N. S. Shaler, Memoirs Boston Soc. Nat. Hist. vol. ii.

³ Cause of the Glacial Period, by Charles Ricketts, GEOL. MAG. Dec. II. Vol. II. 1875, p. 573; Rev. O. Fisher, *op. cit.* pp. 223 and 224.