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AGASSIZ'S INFLUENCE ON GEOLOGICAL THINKING IN THE AMERICAS

BY

Albert V. CAROZZI [1]

ABSTRACT

Agassiz's concept of Pleistocene continental glaciation influenced American naturalists in different ways. The translation in English of his "Discourse of Neuchâtel" in 1838 drew the reaction of Timothy A. Conrad of the New York State Geological Survey, who in 1839 accepted Agassiz's revolutionary idea of immense glaciers over North America. Edward Hitchcock, state geologist of Massachusetts and veteran investigator of diluvial deposits of the Connecticut valley, after reading Agassiz's "Etudes sur les Glaciers" accepted with enthusiasm the glacial theory in 1841. But he had two reservations: he found it difficult to admit a continental ice sheet of such magnitude, and, having mostly worked with outwash material, he was strongly influenced by the role of water. Therefore, he introduced the term « glacio-aqueous" to express his indecision. Finally, by 1843 Hitchcock returned to his initial ideas of a cryptic joint action of currents of water and icebergs.

William W. Mather in his work on the geology of New York (1843) mentioned Agassiz's "glimpse of light", but listed fourteen theories to explain the drift. Samuel St. John in his textbook published in 1851 discussed Agassiz's theory but could not visualize an enormous ice sheet. Finally, in 1859, Charles Whittlesey, on the basis of observations in Greenland and Antarctica, was the first to demonstrate the reality of the continental glaciers in North America as proposed by Agassiz.

When Agassiz arrived in the United States in 1846, he demonstrated by his famous monograph on Lake Superior (1848), and by additional work in the White Mountains and in Vermont, that North America had undergone a glaciation not only contemporaneous with that of Europe but reaching an even greater scale. However, Agassiz made no particular effort to convince American geologists of the truth of his ideas. He had greater plans for himself; he wanted to become, and became indeed, the popular interpreter and describer of natural history to the American people. His success appeared boundless until 1859 when the publication of Darwin's "Origin of Species by means of Natural Selection" forced him to take a stand.

The philosophy of evolution was entirely alien to Agassiz's creationism, and his frantic reaction toward it left him physically ill and intellectually desperate. He felt that if he could demonstrate that the Ice-Age had also extended to the southern hemisphere, it would have severed, on a world-wide basis, all genetic relationships between past and present life, thus disproving any possible

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transmutation of species. This was the real reason for his expedition to Brazil (1865-1866) during which he allegedly discovered evidences of a Pleistocene glaciation extending from Rio de Janeiro to the Amazon. Actually, Agassiz misinterpreted lateritic soils and exfoliation boulders as glacial deposits.

English and American naturalists were dismayed upon hearing of Agassiz's statements which contradicted all other data. It was the last effort of his dogmatic opposition to the theory of evolution. Agassiz never formally retracted his concept of an Amazonian glaciation, but on his subsequent cruise of 1871 to Tierra del Fuego he described with astonishment Pleistocene glaciers as having reached as far as 37° latitude S in a pattern symmetrical with the ice sheets of the northern hemisphere, implicitly invalidating his idea of an equatorial glaciation.

RÉSUMÉ

Le concept des glaciations continentales pléistocènes présenté par Agassiz a influencé de façon très différente les naturalistes américains. La traduction en anglais en 1838 de son « Discours de Neuchâtel » attire l'attention de Timothy A. Conrad du New York State Geological Survey qui en 1839 accepte l'idée révolutionnaire d'Agassiz d'immenses glaciers s'étendant sur l'Amérique du Nord. Edward Hitchcock, géologue d'état du Massachusetts, un investigateur de longue date des dépôts diluviaux de la vallée du Connecticut, après avoir lu les « Etudes sur les Glaciers » d'Agassiz défend avec enthousiasme en 1841 la théorie glaciaire. Mais il a deux réserves: il trouve difficile d'admettre une calotte glaciaire d'une telle grandeur, et, ayant étudié principalement des alluvions périglaciaires, il est fortement influencé par le rôle de l'eau. Par conséquent, il introduit le terme de « glacio-aqueous » pour exprimer son indécision. En 1843, Hitchcock revient à ses idées premières d'une action commune et mystérieuse de courants d'eau et d'icebergs.

William W. Mather, dans son ouvrage sur la géologie de New York (1843), fait mention du « trait de lumière » apporté par Agassiz, mais il décrit quatorze théories pour expliquer l'origine des dépôts quaternaires. Samuel St. John, dans son traité publié en 1851, discute la théorie d'Agassiz, mais à son tour ne peut concevoir une énorme calotte glaciaire. Enfin, en 1859, Charles Whittlesey, se basant sur des observations faites au Groenland et en Antarctique, démontre pour la première fois la réalité d'une calotte glaciaire en Amérique du Nord comme proposée par Agassiz.

Quand Agassiz arrive aux Etats-Unis en 1846, il démontre par sa fameuse monographie sur le Lac Supérieur (1848) et par d'autres travaux dans les White Mountains et au Vermont, que l'Amérique du Nord a subi non seulement une glaciation contemporaine avec celle de l'Europe, mais atteignant une échelle encore plus grande. Cependant, Agassiz ne fait aucun effort pour convaincre les géologues américains de la véracité de ses idées. Il a des projets beaucoup plus grandioses, il veut devenir, et devient en fait, l'interprète populaire et le présentateur de l'histoire naturelle au peuple américain. Son succès apparaît sans limite jusqu'en 1859 lorsque la publication de « L'origine des espèces par sélection naturelle » de Darwin le force à prendre position.

La philosophie de l'évolutionisme étant entièrement opposée au créationisme d'Agassiz, sa réaction frénétique le laisse physiquement amoindri et intellectuellement désespéré. Agassiz prétend que s'il peut démontrer que la période glaciaire s'était aussi étendue à l'hémisphère Sud, elle aurait pu interrompre à l'échelle mondiale toute relation génétique entre vie passée et vie récente, prouvant ainsi l'impossibilité d'une transmutation des espèces. Cette idée est la raison profonde de son expédition au Brésil (1865-1866) pendant laquelle il découvre des soi-disant preuves de l'existence d'une glaciation pléistocène s'étendant de Rio de Janeiro à l'Amazonie. En fait, Agassiz interprète de façon erronée comme dépôts glaciaires des sols latéritiques et des blocs d'exfoliation.

Les savants anglais et américains sont consternés en entendant les affirmations d'Agassiz qui contredisent toutes les autres données. C'est le dernier effort de son opposition dogmatique à la théorie de l'évolution. Agassiz n'a jamais retracté de façon formelle son idée d'une glaciation amazonienne, mais lors de sa croisière de 1871 à la Terre de Feu, il décrit avec étonnement des glaciers pléistocènes ayant atteint 37° latitude S de façon symétrique par rapport aux calottes glaciaires de l'hémisphère nord. Par ce fait il renonce implicitement à son idée d'une glaciation équatoriale.

Louis Agassiz's opening address at the annual meeting of the *Société Helvétique des Sciences Naturelles* on July 24, 1837, marks the beginning of the glacial controversy. Instead of the expected discussion on fossil fishes, Agassiz, then president of the society, presented to its startled members a glacial theory, in which the local erratic phenomena of the Alpine valleys assumed a cosmic significance as part of a glacial period or Ice-Age during which most of the northern hemisphere became covered with a continental sheet of ice, extending from the North Pole to the Mediterranean and the Caspian Sea. [1]

This address, written by a stroke of genius the night before the meeting, was to be called "The Discourse of Neuchâtel." [2] It illustrates one of Agassiz's traits, namely his inclination to frequently rely on his intuition and florid imagination when little factual data was available. Indeed, at this time, Agassiz had not even reached a correct understanding of the Alpine glaciers themselves, but his intuitive awareness of glacial action over half a hemisphere compelled his powerful opponents to critically re-examine their positions and he was eventually proven correct.

While the glacial controversy was spreading all over Europe, in North America geological thinking in that field was virtually at a standstill. American geologists had carefully described the occurrences of "drift," such as polished and striated rocks, outwash deposits and erratic boulders, but their explanations remained confused. The action of powerful marine floods, generated by uplifting of arctic areas, and the effects of icebergs were preferred over a problematic glacial action because nobody could visualize the existence of a continental ice sheet. In fact, confusion had reached a point where many naturalists decided to simply describe the facts and state that they did not understand them.

Agassiz's "Discourse of Neuchâtel" was translated into English and appeared in the *Edinburgh New Philosophical Journal* in April 1838, thus becoming available to the English-speaking scientific community. [3] The first American naturalist to react to it was Timothy A. Conrad of the New York State Geological Survey. Although Conrad was a paleontologist, he was sometimes drawn outside his field of specialty by phenomena too obvious to be overlooked, yet mostly ignored by leading naturalists. For instance, the occurrence of enormous erratic boulders in the drift, resting often upon loose sand and gravel, represented for him such a challenge. His paper, published in the *American Journal of Science and Arts* in January 1839, is a very perceptive refutation of the concept of huge oceanic currents and of icebergs as agents of transportation of erratic boulders. [4] Conrad actually accepts Agassiz's revolutionary idea of "immense glaciers" extending over North America, thus becoming an exception among his confused contemporaries.

In the first part of his article, Conrad discussed the stratigraphic distribution of characteristic fossils as follows: "It is very evident that a change of the mean temperature of the crust of the globe has exerted a marked agency in the destruction of one group of animal life and the creation of another; and it may be owing to this

cause that the higher the organization, the more limited in the geological series are the fossil remains (p. 239)". But Conrad adds:

> I do not conceive it necessary, as M. Agassiz supposes, to infer that in every grand geological epoch, the fall of temperature was so great as to destroy *every* species existing at that time, but that some were, like the human frame, more capable of resisting the influence of cold than others (p. 238).
>
> The fall of temperature has not, as some geologists supposed, taken place gradually since the creation of the globe; but every phenomenon in paleontology goes to prove the existence of a certain mean temperature during a long period and a sudden diminution of heat at particular epochs (Agassiz, *Edinburgh New Philosophical Journal*, April 1838). The change of groups of marine animals was not produced or accompanied by any convulsion, powerful enough to cause a violent rush of the oceanic waters, as the fossils of one period rest upon and even intermingle with those of an earlier date, as if both had lived and died on or near the spots where they are now found (p. 239).
>
> The fall of temperature (so happily illustrated by the genius of Agassiz) which occurred at the commencement of the "Diluvial Epoch," is so well supported by all known facts, that we feel no hesitation in applying the theory to all the inferior grand formations... The phenomena of the "Diluvial Epoch" have long attracted peculiar attention, from the many curious and highly interesting facts which they embrace, and the great difficulty of reconciling them with existing hypotheses. Enormous angular masses, transported perhaps a hundred miles from the parent rock, and reposing on sand and gravel which even a mill stream would have swept away, bid defiance to the mighty currents which so long flourished in the imaginations of certain geologists. Whence came these floods and whither did they go? Such gigantic movements would soon have restored the equilibrium of the waters; and truly they would have been busy during their short reign on earth, to grind down mountains into sand, ... plough deep trenches in the solid rocks, and polish their surfaces with sand.
>
> The boulders rest usually on sand, gravel, or the natural soil, which would necessarily have been swept away, had currents transported these huge fragments, leaving them in every instance reposing on indurated strata. The hypothesis of ice-floes (icebergs) bringing them from the north, floating on the waters of an ocean, and depositing them where they are now found, has been supported by some of the geologists of the present day; but this was in direct opposition to another theory of these same geologists, that a higher mean temperature prevailed over the northern regions at that period, than now reigns in temperate climes (pp. 240 - 241).

Conrad argues that even if the northern half of the continent consisted of an ocean, the temperature could still not be raised as postulated. Therefore, there is no

reasonable hypothesis to account for icebergs as well as for the ocean which allegedly transported them. He then asks the following question:

> Whence then this immense body of ice, which has scattered boulders over so vast a tract of country, appearing too at an epoch subsequent to the existence of the *mastodon* and other mammalia, which evidently lived in this region and enjoyed an equatorial climate anterior to the icy period? Nothing can reconcile this apparent contradiction but the admission of a fall of temperature far below that which prevails in our day, freezing the enormous lakes of that period, and converting them into immense glaciers, which probably continued undiminished during a long series of years (p. 241).

Conrad explains the supply of materials to form ground moraines and erratic boulders in the following manner:

> At the same time, (as the immense glaciers existed), elevations and depressions of the earth's surface were in progress, giving various degrees of inclination to the frozen surfaces of the lakes (read: ice), down which boulders, sand and gravel would be impelled to great distances from the points of their origin. This in some cases might result from gravity alone; but in others, during the close of the epoch, when the temperature had risen, and avalanches began to descend from mountain tops, and from numerous less elevated places, there occurred, on a vast scale, the same phenomena which now are familiar to the travellers among the Alps. Landslides, like that of one of the hills bordering the Saco river in New Hampshire, and avalanches of mud, filled with detritus of all sizes, some angular, as torn from the surface of the rocks, others having been rolled in the beds of torrents would be propelled many miles over the frozen lakes (read: ice); and when the ice disappeared, sand, gravel, pebbles and boulders would be promiscuously together (p. 241).
>
> Mr. Agassiz attributed the polished surfaces of the rocks in Switzerland to the agency of ice, and the "diluvial scratches," as they have been termed, to sand and pebbles which moving bodies of ice carried in their resistless course. In the same manner, I would account for the polished surface of the rocks in Western New York. Running water, carrying sand, gravel, pebbles and boulders, to which cause this smooth appearance has been generally attributed, would not be likely to polish the surfaces of rocks; and moreover, where are those circular cavities, hollowed out by whirlpools, the invariable record of bodies of water moving with the velocity attributed to diluvial floods? I doubt whether any can be found on the polished surfaces of the rocks of the Alpine regions or on the vast horizontal floors of Western New York (pp. 241 - 242).

The influence of Agassiz on Conrad's paper is so striking that even similarities in style can be detected. In some instances, the text seems to have been written by

Agassiz himself when defending his ideas against his powerful European opponents such as Leopold Von Buch.

Agassiz's indirect influence on American naturalists is subsequently transferred to the much respected geologist Edward Hitchcock who had been appointed state geologist of Massachusetts in 1830. [5] Hitchcock wrote very accurate and extensive descriptions of glacial features in the Connecticut valley long before their real origin was understood under the name of "Diluvial Deposits" as shown in his Massachusetts report of 1832 (p. 6) [6], 1833 (pp. 141-172) [7] and 1835 (pp. 148-178).[8]

Agassiz's influence on the thinking of Hitchcock took place through a rather complicated set of circumstances which can best be unravelled chronologically by first recalling the activities of Agassiz himself at that particular time. In September 1840, his *Etudes sur les Glaciers* was published in French and German accompanied by its spectacular folio atlas. [9] In late fall of that same year, Agassiz visited the British Isles and with Reverend William Buckland extended the glacial doctrine to Scotland, Northern England and Ireland. Three abstracts appeared during November and December in the *Proceedings of the Geological Society of London*, authored respectively by Agassiz, [10] Buckland [11] and Lyell. [12]

This group of three abstracts and the *Etudes sur les Glaciers* were going to have a powerful influence, at least initially, on the endeavors of Edward Hitchcock. The latter delivered on April 5, 1841, the First Anniversary Address before the Association of American Geologists at their second annual meeting in Philadelphia. Apparently the original text of the address was never published until a modified version appeared in the issue of October 1841 of the *American Journal of Science and Arts*. [13] This text was reprinted as an individual pamphlet in New Haven at about the same date by B.L. Hamlen.

Hitchcock presents the status of the investigation of drift in the United States as follows:

> Excepting the remarkable insulated labors of Mr. Hayden, the drift, or diluvium of this country, has, until recently, received less attention than almost any other formation. The same has been true in Europe. This results in part from the fact, that it cannot be successfully studied until the characters and limits of all the subjacent formations are well understood. The state surveys, however, have brought to light enough of our diluvial phenomena to show us, that though a difficult subject, it is one of the most interesting in the whole history of our rocks.
>
> It is an important inquiry, whether the phenomena of drift in this country correspond with those of the eastern continent. Until recently, I confess, I have doubted whether some of the most striking of these phenomena were not much more fully developed here than in most countries of Europe. I refer particularly to the smoothing, polishing, scratching and furrowing of the rocks in place, and

to those accumulations of gravel, bowlders, and sand, which form conical and oblong tumuli with tortuous ridges of the same, and which abound in the northern part of the country, from Nova Scotia to the Rocky Mountains. But the recent investigations and accurate descriptions by Agassiz, Buckland, Lyell, Sefstroom, and others, have satisfied me of the almost exact identity of the facts in relation to drift on the two continents. The resemblance, however, seems to be most complete in this respect between Scandinavia and this country. Except in Sweden, I have not yet seen evidence that scarification of the rocks is as common in Europe as in New England, where if they were denuded of soil it seems to me, one third of the surface would be found smoothed and furrowed. But it is now found to be very common in Scotland, England and especially in Switzerland. It appears too, that those countries abound in those peculiar accumulations of gravel and bowlders to which I have referred, and which are now regarded as ancient *moraines*. Bowlders, also, appear to have been dispersed in a similar manner on both continents (pp. 247-248).

Hitchcock proceeds then to enumerate the major features of drift and the inferences to be related to them. Some general force or forces, operating in the same general direction from sea-level to 3 to 4000 feet, becoming less powerful southwards and acting over a continent having essentially reached its present elevation. Water must certainly have been one of the active forces, in particular to explain the regularly stratified deposits of clay and sand which form the upper part of the diluvial deposits. Such sediments must have been accumulated in large bodies of water, subsequently drained. Hitchcock considers that erratic boulders have been transported hundreds of miles by the aid of water although this alone could not be sufficient. He is convinced that water, on the other hand, cannot be responsible for the smoothing and furrowing of rocks and that another agent has to be considered. Finally, he assumes the action of ice as the transporting agent of large blocks and gravel over wide areas and on top of mountain ridges, as well as the agent responsible for the production of the singular mounds and peculiar ridges of gravel and boulders. In conclusion, these phenomena occured before the existence of man, argues Hitchcock, they destroyed organic life almost completely, yet the events took place at a comparatively recent time. Finally, the responsible agent must have been far more powerful than any one now operating upon the globe.

This synopsis of Hitchcock's position before undergoing the full effect of Agassiz's ideas indicates clearly a state of confusion typical of American geologists dealing with the drift who would not effectively distinguish the action of water from that of ice.

Hitchcock's address continues as follows:

Beyond such independent inferences as these, I confess I have been of late years unwilling to go; and have regarded the numerous theories of diluvial action,

which have recently appeared, only as ingenious hypotheses. But it is well known that the *Glacial Theory*, originally suggested by M. Venetz and subsequently adopted by M. Charpentier, and more fully developed of late by Agassiz, is now exciting great interest in Europe. To say nothing of geologists in this country who have expressed themselves favorably towards it (See Mr. Conrad's Notes on American Geology, *Am. Jour. Sc.*, XXXV, p. 237); it is surely enough to recommend it to a careful examination, to learn that such men as Agassiz, Buckland, Lyell and Murchison, after long examination, have more or less fully adopted it; although on the other hand, it ought to be mentioned, that such geologists as Beaumont, Sedgwick, Whewell, Mantell and others, still hesitate to receive it.

In a country like ours, where no glaciers exist except in very high latitudes, and with the very defective accounts which have hitherto been given of those in the Alps, it is not strange that the attempt to explain the vast phenomena of diluvial action by such an agency, should appear at first view, fanciful, and even puerile. But the recent work of Agassiz, entitled *Etudes sur les Glaciers*, gives a new aspect to the subject. It is the result of observations made during five summers in the Alps, especially upon glaciers, about which so much has been said, but concerning which so little of geological importance has been known. Henceforth, however, glacial action must form an important chapter in geology. While reading this work and the abstracts of some papers by Agassiz, Buckland and Lyell, on the evidence of ancient glaciers in Scotland and England, I seemed to be acquiring *a new geological sense*; and I look upon smoothed and striated rocks, our accumulations of gravel, and the *tout ensemble* of diluvial phenomena, with new eyes. (pp. 252-253).

Hitchcock apologizes for the changes he made to his address after it was delivered, in a footnote, at the bottom of page 253 which reads as follows:

I trust that the members of the Association will pardon me for having made some alterations in the form, though not in the leading thoughts, of this part of my Address, since it was delivered. They will recollect, that while I expressed a very favorable opinion of the Glacial Theory, so far as I understood it, I stated that I had not seen the work of Agassiz named in the text. Through the kindness of Prof. Silliman, I have since been favored with the perusal of the copy of this work, with its splendid alpine illustrations, he received from the author. I am indebted, also to Dr. J. Pye Smith, of London, for an abstract of the papers of Agassiz, Buckland and Lyell, read before the London Geological Society last autumn, on the ancient glaciers of Scotland and England. A flood of light having thus been unexpectedly thrown in upon my mind, I am free to acknowledge that many of my difficulties in respect to this theory have been removed, and that the great mass of evidence in its favor, thus brought before me, has led me to express a warmer admiration of its leading features

and a greater readiness to adopt its leading principles, although satisfied that it will need important modifications.

It seems obvious now that while addressing the Association of American Geologists on April 5, 1841, Hitchcock had not seen the *Etudes sur les Glaciers* but knew enough about the glacial theory to have reached a favorable opinion toward it. Therefore, his sources of information would have been Conrad's paper of 1839 and the English translation of the "Discourse of Neuchâtel" published in the April issue of the *Edinburgh New Philosophical Journal.* In October 1841, when the modified text of his address was published, he had seen the *Etudes sur les Glaciers* as well as the abstracts of the papers presented in the fall of 1840 by Agassiz, Buckland and Lyell pertaining to the introduction of the glacial theory in the British Isles; hence his change of mind and the urgent necessity of altering parts of his address.

Hitchcock is however not totally convinced and some reservations appear already when, in his address, he tries to apply the phenomena of drift to America. One of the reservations is the southerly direction of transportation of the drift and the great distance to which it has been carried, particularly over a surface which did not have any distinct slope in that direction. Yet, he agrees that if the ice sheet were thick enough, such a transport could be visualized. Another point was Agassiz's assumption that the fall of temperature at the beginning of the glacial period was very sudden. Why would not the return of heat have been equally rapid? In such a case, abundant water generating powerful debacles could have set up a direction of transportation toward the south. Apparently, Hitchcock seems to prefer the action of water rather than ice, a dilemma that will plague him for a long time to come. Another difficulty lay in the fact that the drift had been carried from lower to higher levels; again Hitchcock argues that this could be another result of a thick ice sheet. A further problem arose with those moraines which were most prominent and consisted of conical and oblong tumuli of drift (in fact kames) found hundred miles away from any mountains higher than themselves in Plymouth and Barnstable Counties in Massachusetts. In that respect he writes:

> I see nothing in the glacial theory that will explain such astonishing accumulations in such circumstances; and yet their existence may not militate against its truth. For even the present mighty glaciers of the Alps, may give us but a faint idea of the effects of the advance and retreat of a sheet of ice thousands of feet thick. We have no evidence in this country, that any of our mountains have been elevated since the glacial epoch; as seems to be proved to have been the case with the Alps, and this circumstance may have produced a considerable modification of glacial action on this continent (pp. 257-258).

In the conclusion of his address, Hitchcock attemps a compromise in the following manner:

> I do not mention these difficulties (to which I might add more) as any strong evidence against this theory. For so remarkably does it solve most of the phenomena of diluvial action, that I am constrained to believe its fundamental principles to be founded in truth. Modifications it may require: for it would be strange enough if it had already attained perfection, even in the skillful hands that have thus framed and fashioned it. But I can hardly doubt that *glacio-aqueous* action (by which I mean the joint action of ice and water, without deciding which has exerted the greatest influence) has been the controlling factor in producing the phenomena of drift. Having hovered so long over the shoreless and troubled ocean of uncertainty and doubt, I may be too ready to alight on what looks like *terra firma*. But should it prove a Delos, I have only to plume my wings again, when it sinks beneath the waves (p. 258).

As a whole Hitchcock's address is a fairly enthusiastic acceptance of Agassiz's glacial theory with two major reservations. First, he had some understandable difficulties in admitting a continental ice sheet thick enough to account for all the observed facts. Second, he was naturally under the strong influence of his own investigations in the Connecticut valley, where most of the glacial occurrences are outwash materials, kames, kame terraces, etc., in which stratification suggests to the mind more the action of water than that of ice. This is the reason for his constant use of the term "glacio-aqueous," a term expressing his indecision rather than a positive contribution to the problem.

A similar evolution of thinking is displayed in Hitchcock's *Final Report on the Geology of Massachusetts*, [14] one of his major contributions to geology. Although the terms are different and Agassiz is even given a more glowing treatment, his indecision remains unchanged. The "Final Report" was presented to the governor of the State on December 1, 1839 (pp. IV and VII), but published only near the end of 1841. It may be inferred from what has been related above that important events took place during that span of time requiring also appreciable changes of the text as originally submitted.

In the main text of the "Final Report," a section (pp. 350-407) is dedicated to the Diluvium or Drift. It begins as follows:

> I shall probably be thought by some, either ignorant of the present state of geology, or unreasonably tenacious of former opinions, by retaining the term *Diluvium*, to designate that coating of gravel, sand and clay, covering the surface almost everywhere, and resulting from aqueous agency between the deposition of the tertiary and alluvial strata. By doing this, I do not intend to advocate the opinion that all this deposit was the result of one transient universal deluge. But in New England, the greater part of it certainly appears as if the result of powerful currents of water, rushing over the surface in the manner of a deluge.

After a careful description of the features of drift, Hitchcock reviews the theories of diluvial action (pp. 403-406) and writes as follows:

> A theory has been lately started to explain the diluvial phenomena, founded on the action of glaciers in the Alps. Though not originally proposed, it has been chiefly elucidated and defended by the distinguished naturalist, Agassiz, of Neuchâtel in Switzerland. That it may explain the movements of detritus in the Alps, which for the most part appears to have been carried outward from the axis of the mountain, I am not disposed to deny.

But Hitchcock is unable to see how this agency can account for most of the features of drift as displayed in North America and he gives essentially the same list of phenomena mentioned in his address. He ends his discussion by saying:

> I confess I have as yet seen only a very brief and evidently imperfect development of this theory, in one or two short notices in the scientific journals. But as I understand it, it seems to me inadequate to explain the *tout ensemble* of diluvial phenomena. To my mind, therefore, no theory of diluvial action hitherto proposed, is so free of objections that I feel satisfied with it. That remarkable and very powerful currents of water have swept over this continent from the north and northwest, I cannot doubt.

On April 1, 1841, better informed as mentioned above, Hitchcock will add a note to his "Final Report" stating: "It may be proper to say, that the great length of time which has been necessarily consumed in printing the following Report, has enabled me to discover many facts since it was first presented to the Government. These I have not hesitated to incorporate into the work, as the reader will see, without consulting the Government." (p. IV)

This addition of new facts took the form of a Postscript, preceding the main body of the text and included a section entitled "Glacio-aqueous Diluvial Action" (pp. 3*a*-11*a*). It begins in the following terms:

> Since the Section in this Report on Diluvium was written, I have been favoured, through the kindness of Professor Silliman of Yale College, with the perusal of a recent work of Professor Agassiz on Glaciers and Glacial Action, entitled *Etudes sur les Glaciers*. I am also indebted to Dr. J. Pye Smith of London, for an abstract of three papers on the same subject, read last autumn before the London Geological Society, by Agassiz, Buckland and Lyell. By the labours of these distinguished men, the whole subject of diluvium has been made to assume an aspect so new and interesting, that I am unwilling my Report should go out of my hands unaccompanied by a brief view of the facts and inferences concerning it. Perhaps I cannot better accomplish this object, than by giving, in the

first place, an outline of the glacial theory, and its application to this country, in an extract from an Address recently published which I gave before the Association of American Geologists at Philadelphia in April 1841 (p. 3*a*).

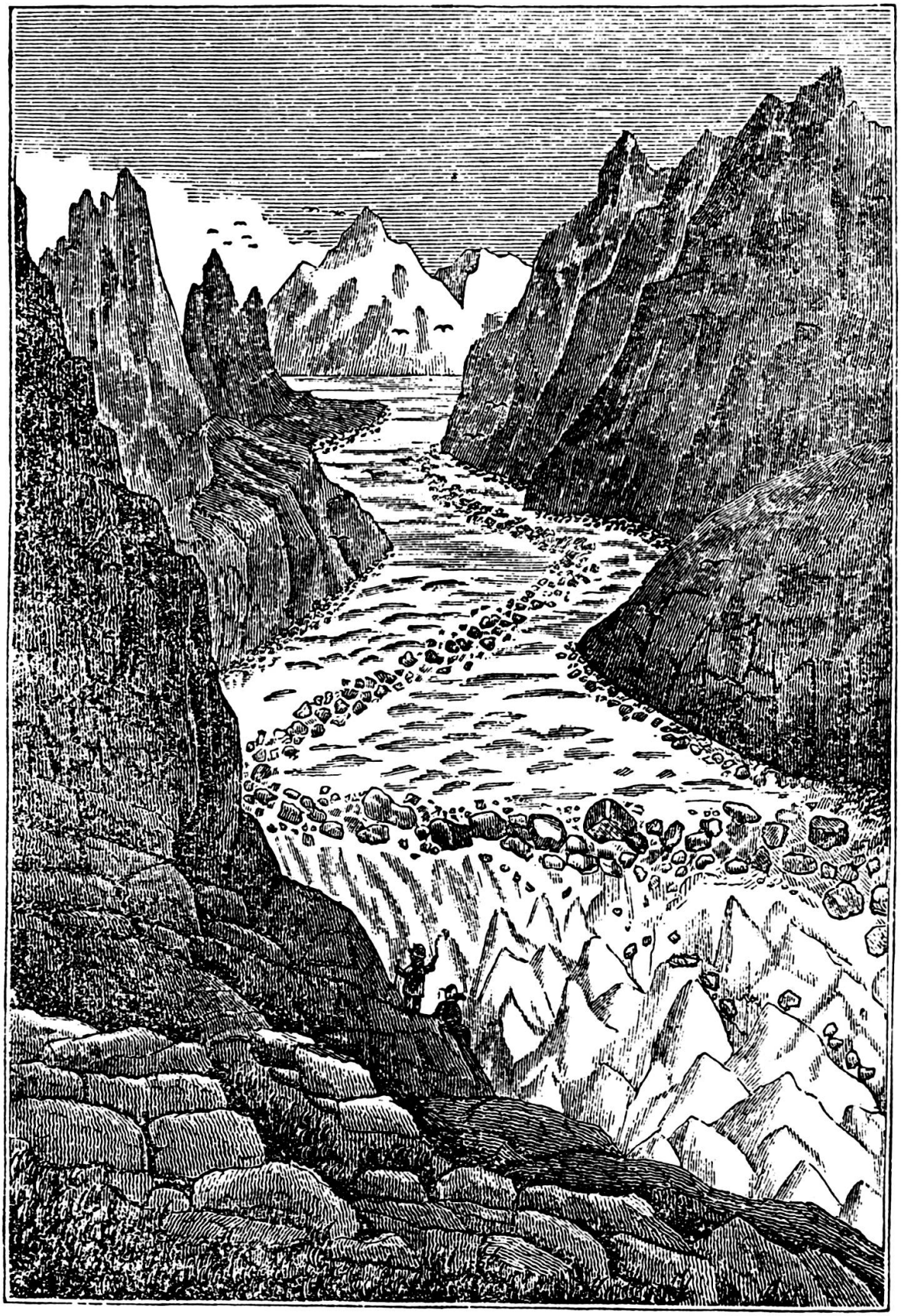
The Postscript is made even more valuable by the insertion of a few cuts, copied on a reduced scale from the splendid drawings accompanying the *Etudes sur les Glaciers*. Hitchcock actually reproduced plates 9, 10, 12 and a portion of plate 18 of the folio atlas which accompanies Agassiz's text (fig. 1). Hitchcock concludes his presentation of the glacial theory as follows:

> The theory of glacial action has imparted a fresh and lively interest to the diluvial phenomena in this country. It certainly explains most of these phenomena in a satisfactory manner. It seems to me, however, that the term *Glacio-aqueous* action more accurately express this agent than the term glacial action: for the effects referrible to water are scarcely less than those produced by ice. I could wish that the theory gave a more satisfactory explanation of the southerly direction taken by the drift. Perhaps this is a point which can only be hypothetically solved.

Hitchcock continued his investigations of the drift in Massachusetts, and at the second annual meeting of the Association of American Geologists and Naturalists, at Boston, he presented, April 26, 1842, a paper on his favorite subject.[15]

This long article, published in 1843, mentions repeatedly the "lucid descriptions of Agassiz" (p. 175) and concerning the embossed rocks found near the top of Mount Monadnoc, in New Hampshire, Hitchcock writes: "I confess, however, that if I had not read Agassiz's description of this phenomenon in the Alps, I should have failed to discover it on this mountain" (p. 181). In his discussion of the fact that the White Mountains have been covered by drift, Hitchcock quotes in a footnote dated January 1, 1843, Agassiz's description of high mountains in Scotland having their summits as polished as their flanks, whereas in the center of the Alps, above 9000 French feet, the summits are no longer polished. [16] Unquestionably, Hitchcock is keeping himself well informed, nevertheless his reservations are increasing with time and he concludes his paper by maintaining his point of view of glacio-aqueous agency considering the glacial theory alone as inadequate to explain the facts in North America (p. 218).

Hitchcock's excitement about the glacial theory declines more and more, to the extent that he deeply resents being associated with any of Agassiz's ideas. This sensitivity is demonstrated by the controversy which arose between him and Sir Roderick Murchison. It should be recalled that Hitchcock in his Anniversary Address of April 5, 1841 at Philadelphia, mentioned Murchison among those who had "more or less adopted the glacial theory" (p. 252). In fact, Murchison was not converted; not even "more or less" to the glacial theory and he reacted vigorously in his own



Glacier of Viesch in the Alps.

FIG. 1. — Reproduction of plate 10 of Agassiz's folio atlas
of the *Etudes sur les Glaciers* (1840)
in Hitchcock's *Final Report on the Geology of Massachusetts* (1841),
Postscript, p. 6a, fig. 277.

Anniversary Address of 1842 as President of the Geological Society of London [17] as follows:

> ... so long as the greatest number of practical geologists of Europe are opposed to the wide extension of a terrestrial glacial theory, there can be little risk that such a doctrine should take too deep a hold of the mind. But whilst we may have no fear of this sort in Europe, I have lately read with regret certain passages in the Anniversary Discourse of Professor Hitchcock of the United States. In North America, striated, scored, and polished surfaces of rocks, proceeding from N. to S. for vast distances, occupy, it appears, at intervals a breadth of 2000 miles, and are seen on hard rocks at all levels from the sea-shore to heights of 3000 to 4000 feet. Professor Hitchcock tells us, that these phaenomena and the accumulations of gravels and blocks had always been inexplicable, until the work of Agassiz unexpectedly threw a flood of light upon his mind (Anniversary Address, Philadelphia, April 1841, p. 24). I must be excused for stating that Professor Hitchcock has entirely misconceived my views when he places my name along those who have espoused the Alpine glacial theory. My efforts have been invariably directed towards its limitation, nay, to its entire rejection as applicable to by far the largest portions of the surface of the globe. If Professor Hitchcock could demonstrate what he now seems to believe, that the great mass of the continent of North America was formerly covered with ice, he must first prove that it was not at that period below the level of the sea; but as yet no facts are before us to lead us to doubt that the great accumulation of detritus and the transport of blocks did take place beneath the waters in that country. In justice, however, to this author, it must be said, that in expounding the glacial theory, he ingeniously acknowledges the great difficulty in believing that solid masses of ice, 3000 to 4000 feet thick, covered the whole region; that no action of a glacier will explain the persistent striation of the surface of an entire *continent* from N. to S., and that the direction of the boulders and the striae is to a great extent up-hill. When these and many other difficulties shall have been carefully weighed, our transatlantic friends may be disposed to modify their views, particularly when they find that the existence of glaciers in Scotland and England (I mean in the Alpine sense) is not yet, at all events, established to the satisfaction of what I believe to be far the greater number of British geologists (p. 683).

Hitchcock was stung and replied in a footnote on page 218 of his paper of 1843 mentioned above. The note reads as follows:

> I regret to find that the President of the London Geological Society, (see Mr. Murchison's Address before that Society in February, 1842) has understood me in my Address before the Association of American Geologists, to be commited to the unmodified glacier theory of Agassiz. Much more do I regret that

> he seems to identify the views of American geologists with mine. I did, indeed, express myself strongly in my admiration of the ingenuity and ability with which the subject was treated by that distinguished naturalist, and in my joy at the new light which the history of glaciers seemed to me to shed upon the phenomena of striated, smoothed, and embossed rocks, and the formation of moraines; but I certainly never imagined that his theory, *unmodified*, would explain the phenomena of drift in our country. And this I stated three times in that Address. I also stated what was the grand conclusion to which my mind had come in view of all the facts; namely, that "glacio-aqueous action (by which I mean the joint action of ice and water, without deciding which has exerted the greatest influence,) has been the controlling power in producing the phenomena of drift." My general views on this subject were the same when I wrote my Address, as when I wrote this paper; except that in the latter, they are more matured and carried out into details.

To sum up this controversy, it appears that Hitchcock had indeed been too quick in 1841 in including Murchison among the supporters of the glacial theory. On the other hand, Murchison in his critical review of Hitchcock's address failed to stress the reservations the latter always had in spite of his temporary enthusiasm for Agassiz's ideas, and that he expressed by coining the term of "glacio-aqueous action" as the controlling factor in producing the phenomena of drift in North America.

From 1843 on, Hitchcock will suggest that the ultimate theory of drift should be a combination of all proposed explanations: icebergs, elevations and earthquake waves and glaciers. This attitude will lead him to propose such an unsatisfactory combination in the later editions of his textbook [18, 19] which appeared throughout a twenty-four year interval starting in 1840.

While the above discussed evolution was taking place in the mind of Hitchcock, mainly as the effect of a single copy of the *Etudes sur les Glaciers* belonging to Benjamin Silliman, an extensive review in English of this volume appeared in the United States in 1842 [20] and apparently drew no attention from the scientific community. It seems indeed surprising that so little reaction took place among American geologists working on the Drift at a time when the two leading works of Agassiz on the glacial theory had become available. The review is introduced by a footnote of the editors of the *American Journal of Science and Arts* which reads as follows:

> This article is republished from a little tract which Mr. Maclaren had the kindness to send us, entitled "The Glacial Theory of Professor Agassiz of Neuchâtel, being an outline of facts and arguments adduced by him to prove, that a sheet of ice enveloped the northern parts of the globe at a recent geological epoch; by Charles Maclaren". As it is the best review of the subject

which has met our eye, we deem no apology necessary to our readers for republishing it here.

One of the editors, it should be recalled, was Professor Benjamin Silliman who loaned his copy of the *Etudes sur les Glaciers* to Edward Hitchcock the year before.

Maclaren's paper is a well-balanced review of the *Etudes sur les Glaciers* combined with the translation of the *Discourse of Neuchâtel* as printed in the *Edinburgh New Philosophical Journal* of 1838 and with Agassiz's ideas on glaciation in Northern England and Scotland as expressed by the latter in the *Proceedings of the Geological Society of London* in 1840. The article is also illustrated by nine little sketches, one of which (Fig. 4) is taken from Plate 14 of Agassiz's folio atlas.

Maclaren expresses a few reservations on Agassiz's theory at the beginning and at the end of his review as follows: "Even though Mr. Agassiz's opinions should not be fully established, they still afford us a new geological agent of great power and widely applicable, which may help us to an explanation of some phenomena very difficult to account for with our existing means of information." (p. 347) And at the end: "These very original and ingenious speculations of Professor Agassiz must be held for the present to be under trial. They have been deduced from a limited number of facts observed by himself and others, and skillfully generalized; but they cannot be considered as fully established till they have been brought to the test of observation in distant parts of the world, and under a great variety of circumstances." (p. 365)

The author of this review mentions an interesting result of continental glaciation which Agassiz did not consider, namely the lowering of sea-level that he estimates at 800 feet. He writes as follows:

> Assuming that about ⅛ of the water still remains locked up in the existing polar ices, it means that the melting of the portion which has disappeared today would have raised sea-level nearly 700 feet. Naturally, the very uncertain element is the real thickness of the ice, but even if it should be reduced to one-half, we would still have an agent capable of producing changes of sea-level of the order of 350 feet. This calculation leaves out the southern polar regions, if they were also covered with ice the change would be much greater. (p. 365)

The present day figure is about 250 feet of lowering of sea-level during each glaciation.

Charles Maclaren (1782-1866) was a Scottish clerk and editor entirely self-educated with a strong interest toward the geological sciences. [21] In his review (p. 351) he mentions to have accompanied Mr. Agassiz "about two months ago" (in fact October 27, 1840) to a quarry on the south side of Blackford Hill, near Edinburgh to examine a striated clinkstone pavement, upon the sight of which Agassiz instantly exclaimed, "that is the work of ice!" This episode dates the review as late 1840 or early 1841. Before having been exposed to the influence of Agassiz,

Maclaren had written a book on the geology of the vicinity of Edinburgh [22] in which striated rocks were still attributed to the action of water currents, possibly oceanic waters and the erratic boulders to icebergs.

Another evidence of Agassiz's influence on geological thinking in America may be found in the work of William W. Mather on the geology of New York. [23] In its preface (p. IX), talking about Drift, he mentions "a glimpse of light" which occured in 1841 which seems to refer to Hitchcock's First Anniversary Address and its excitement about the glacial theory. Under the heading of Drift (pp. 158-228), Mather gives no less than fourteen theories to explain the occurrence of striated surfaces and erratic boulders. Under number 9 he writes: "Mr. Agassiz, the distinguished naturalist, is now attracting much attention by his attempts to explain the transport of boulders and blocks and the scratched surfaces, by the effects produced by *glaciers* in the Alps and other mountain regions, and applying them to the phenomena observed in England, Scotland, etc. ..." Nevertheless, Mather concluded that the transport of drift materials and the production of scratched surfaces were contemporaneous, the drift being transported in part by currents and in part by ice, the latter drifted by the currents.

Agassiz's influence still lingers in a short paper read by Hitchcock on May 14, 1844, before the Association of American Geologists and Naturalists in Washington. [24] This paper describes a remarkable train of glacial boulders extending from Fry's Hill in the Canaan Mountain of New York for a distance of about fifteen to twenty miles, southeastwards into Massachusetts, and commonly called the Richmond Boulder Train. Hitchcock compares it to the medial moraines of glaciers in the following terms:

> ... that is, trains of blocks borne along on the back of the middle of the glacier, in consequence of the union of two glaciers whereby the lateral moraines of the separate glaciers are forced to the surface after the coalescence. One has only to look at such moraines, as represented by Agassiz in his *Etudes sur les Glaciers*, to see that they a good deal resemble the trains of blocks in Richmond; and then, such a mode of transport would show why they are not rounded. (p. 264)

But Hitchcock could not conceive of a glacier moving directly across intervening ridges even if the mountains in the vicinity were high enough to have generated a glacier. The consideration of a river depositing drift or of floating ice did not satisfy him either and he concluded: "In short, I find so many difficulties on any supposition which I can make, that I prefer to leave the case unexplained till more analogous facts shall have been observed." (p. 265)

There is a final sequel to Hitchcock's work. His reports were widely distributed and well known to Samuel St. John, professor of chemistry, mineralogy and geology in Western Reserve College, then located at Hudson, Ohio. [25] St. John was engaged

in the preparation of a textbook which appeared in 1851. [26] In it, the author describes and discusses the work of glaciers (pp. 25-28) and includes illustrations of a glacier, of striations and of an iceberg. The picture of a glacier (Fig. 21) is entitled, "The glacier of Viesch with medial and lateral moraines," and is but a reproduction of Hitchcock's copy of Agassiz's original plate 10 of his folio atlas. St. John's figure 13, "Striae of glaciers," is most certainly taken from an actual sample from Ohio. This discussion of the action of glaciers is given under the heading of "Aqueous Agencies" and pertains to the physical portion of the textbook. The features of the drift are described without any particular interpretation in Chapter IX (pp. 223-251) under the heading of "Rocks of the Quaternary Period" divided into "The Drift Period" and "The Alluvium," both representing the end of the section of the book corresponding to historical geology of today. The "Theories of the Drift" are discussed in Chapter X "Theoretical Geology." While the iceberg theory and the elevation theory are rejected as insufficient, the glacier theory gets the following fair treatment:

> The *glacier theory* supposes that the climate, which in the Tertiary period had been so warm as to allow the palms to grow within the temperate zones, became much colder, causing enormous sheets of ice—polar glaciers—to advance far beyond their previous limits, moving along the surface by alternate advance and retreat, rounding, polishing and striating the rocks, and afterward when melted depositing their loads of boulders and detritus, where the drift is now found. In Europe the center of expansion is supposed to have been the Scandinavian mountains, and in North America in the polar regions, from which the glaciers advanced southerly.
>
> The advocates of this theory contend that the phenomena of glaciers as witnessed in the Alps (§ 32) are perfect miniature representations of the drift—its striae, furrows, boulders and moraines; that the elevation of extensive regions in high latitudes, like those of the Cordilleras in Mexico, and the high plains of Central Asia, would produce such a reduction of temperature as to cause immense glaciers, even thousands of feet in thickness. This theory is advocated by Prof. Agassiz.
>
> The principal objection to the glacial theory is that glaciers are at present entirely confined to valleys, and the origin of such an enormous sheet of ice as it contemplates is altogether hypothetical.
>
> Neither of these theories is deemed quite satisfactory; the proximate cause of the phenomena is very generally supposed to have been the joint action of ice and currents of water, but their origin and exact modes of operation are not determined (pp. 255-256).

For the time being, St. John, like most of his contemporaries, interprets the Drift as deposited by a cryptic association of ice and currents of water and "the

enormous ice sheets" are left out. But the critical year of 1859 is approaching when Charles Whittlesey on the basis of observations recently made available from Greenland and the Antarctic will be among the first to attempt comparisons between such phenomena and the drift in North America. [27, 28] He writes as follows:

> Without entering at large into a discussion of the drift force, I assume for the present purpose that, in the early periods of the drift epoch, it was *glacier ice*. Nothing else seems to be equal in energy to the results we observe. A strong objection to this view has been removed by the observations of Dr. H.H. Hayes, of the Kane Arctic Expedition.
>
> On the north-west coast of Greenland, which is a vast glacier, the ice was found to be progressing toward the coast over a country that was comparatively level. It had a movement not only down inclined surfaces, such as the slopes of mountains, but along flat land, and even up inclinations that were opposed to its progress. If the temperature of Greenland or the Arctic Circle was brought down to latitude 40° north, glaciers would exist. Regarding the explanations of Agassiz and Desor as to the cause of the motion of glaciers to be correct, that it is not wholly due to gravity, there is nothing improbable in such a movement over a level country... (p. 299).

Subsequently and gradually the glacial theory with its huge ice sheets, as originally postulated by Agassiz will become accepted in North America.

It is appropriate to focus now on Agassiz's arrival in the United States in order to find out if and how his influence on American geologists increased through personal contact, as one might expect. He arrived in America in September 1846, appointed professor of geology and zoology at Harvard University. [29] The moment he landed at Halifax he was met by the familiar features such as polished rocks, furrows and scratches so well known to him in the Old World and convincing him that the great glacial action had been at work also in North America. At once, he began to apply his ideas to the phenomena of drift. In the summer of 1848 he undertook with Jules Marcou and a group of students his famous Lake Superior expedition [30] to study all fields of natural history. After having investigated the glacial phenomena so beautifully exposed in that area, Agassiz stated his conviction that the drift of all northeast America and northwestern Europe was contemporaneous and deposited by a general sheet of ice. Repeating his former arguments, he showed that a current of oceanic water capable of transporting the large erratic boulders would have swept the entire world and that water-transported materials would not striate and scratch rock surfaces. Furthermore, he rejected the concept of icebergs which would have required a period of cold producing not only icebergs but be sufficient to create the much more effective mechanism of the continental icecap that he postulated.

Unfortunately, in spite of his keen understanding of most of the aspects of continental glaciation, Agassiz, particularly in the case of Lake Superior, did not understand the intimate relationship between till and fluvioglacial sediments such as those of kames; in essence he did not fully grasp the importance of glacial meltwater, a facet which American geologists over-emphasized, preventing them to visualize the continental glaciers.

Further data collected in the White Mountains and in Vermont added to Agassiz's conviction that North America had undergone a glaciation not only contemporaneous with that of Europe, but reaching even a much greater scale. But Agassiz did not take an active part in attempting to convince North American geologists of the truth of his ideas although he would certainly have found a receptive audience. He did not challenge his opponents in journals and meetings as he had done in Europe. In fact, one may state that Agassiz had more influence on North American geologists before his arrival in the States than afterwards. This behavior seems strange, at first glance, but further investigations show this lack of involvement to be directly related to the grandiose projects Agassiz wanted to accomplish in the United States compared to which the task of convincing a few American geologists of the truth of continental glaciation seemed a rather trivial undertaking.

Indeed, Agassiz wanted to become the leading naturalist of America by writing a series of volumes covering the entire field of natural history; he also wished to be an inspiring teacher and the personification of science by giving popular lectures and by creating a museum. His ultimate purpose was to demonstrate how the advancement of science would benefit the developing American civilization, a goal very much in favor with the American people of that time. He essentially succeeded in all his projects by starting in 1847 his famous lectures at the Lowell Institute on "The Plan of Creation, especially in the Animal Kingdom," by the preparation and publication of several volumes of his "Contributions to the Natural History of the United States," the first of which was published in 1857, by creating his Museum of Comparative Zoology dedicated in 1860 and finally by his active participation in the foundation of the National Academy of Sciences in 1863.

Agassiz had become the popular interpreter and describer of natural history to the American people and his success seemed boundless when in 1859 the publication of Darwin's *Origin of Species by means of Natural Selection* [31] forced him to take a stand, to assess Darwin's contribution, in other words. The philosophy of evolution as defined by Darwin was entirely alien to Agassiz's metaphysical concepts and a clash of major proportion developed. Agassiz was a catastrophist who believed in a completely premeditated plan of the organic and inorganic world, all aspects of which would express the continuous and direct intervention of a personal and intelligent God. This divine will is responsible for the discontinuities (such as the Ice-Age) as well as for the repeated creations of immutable life forms at specific times and places. According to Agassiz's beliefs there was neither evidence of transformation

of one species into another nor of any development from lower to higher forms. Obviously, Agassiz's special creationism was entirely incompatible with any transmutation of species.

In addition to these fundamental differences, Agassiz's numerous lectures to the public at large gradually increased his dogmatism while leaving him little time to analyse and assess the new theory that his colleagues were eager to try. In fact, he began to care less and less about their opinions, and if his *Essay on Classification* [32] (1859) is to be considered as a reply to the *Origin of Species*, then it is clear that Agassiz was not interested in any new approach and that he was simply answering new challenges by old arguments. Actually, by 1861, Agassiz had virtually isolated himself from the scientific mainstream of his time. His critics were baffled at a man who could make the most fascinating discoveries by skillfully applying the scientific method, and then would destroy the scientific value of the data by interpreting them through a rigid and obsolete creationism.

Apparently this was the first time that a feeling of defeat entered the mind of Agassiz who had previously known nothing but success and who had considered himself the most outstanding naturalist of the nation, if not of the world. Since he could not convince his colleagues of the fallacy of the evolution theory, he felt it was his duty to fight this new idea by means of his earlier and successful formula of popular lecturing and writing.

He ceased to publish in professional periodicals, but entered a period of feverish activities. After lecturing first at Utica, New York, he returned in the winter 1861-1862 to the Lowell Institute. His lectures were combined with extensive publication in the *Atlantic Monthly* throughout 1862, all of which was incorporated in 1863 in a volume entitled *Methods of Study in Natural History*. [33] This book became Agassiz's most popular work and went through nineteen editions between 1863 and 1884. Further lecturing at the Brooklin Academy of Music led to a second volume in 1865: *The Structure of Animal Life*. [34] Still another series of twelve articles in the *Atlantic Monthly* published between March 1863 and July 1864 dealing with geology and paleontology were combined in book form as *Geological Sketches* [35] in 1866. In five years, Agassiz had given three lecture series and written 21 articles and three volumes, all supporting with great vigor his concept of special creationism.

In September 1864, he found time for a fieldtrip to Maine to examine drift phenomena on the islands and coasts of that state. The trip undertaken after some first signs of illness had an invigorating effect on Agassiz and proved to be one of the most interesting in this country with reference to local glacial phenomena. His results, published in 1867, again in the *Atlantic Monthly* [36] apparently remained unnoticed by American geologists.

During the winter of 1864-1865, Agassiz's health began to fail and sure signs of a nervous breakdown appeared. Unquestionably, his numerous activities, the evolution quarrel, internal difficulties in his museum were taking a heavy physical and

psychological toll. Still, he gave another series of lectures at the Lowell Institute in which he used the action of an alleged continental glaciation in South America, wiping out all life, as a further argument against evolution.

Agassiz's interest in South America represents a turning point in his career which invites speculation. Indeed, in the northern hemisphere he had demonstrated the reality of continental glaciers during the Ice-Age and used them to represent divinely inspired catastrophes that wiped out all life and cut off all genetic relationships between past and present life. However, this process involved only a portion of the world, leaving the southern hemisphere essentially unaffected. He feared that possibly in such areas someone could find arguments in favor of the theory fo evolution. Apparently, Agassiz could not stand this uncertainty; if he were to find traces of the Ice-Age in Brazil, that is *in the tropics*, then the Pleistocene glaciation would really be the cosmic and divinely controlled catastrophe disproving on a *worldwide basis* the possible transmutation of species. In the absence of any written documents, this seems to be the most plausible motivation of Agassiz's interest in South America, an interest which would lead him toward the most spectacular failure of his scientific career.

In his last lecture at the Lowell Institute, Agassiz stated that it would be a great contribution to science if a naturalist would explore Brazil and the Andes in order to find actual evidence of glacial action besides collecting data on natural history of this vast and little-known region.

Nathaniel Thayer, a trustee of Agassiz's museum and one of the wealthiest businessmen of Boston realized that an expedition to Brazil would allow Agassiz not only to regain his health but also to make new scientific discoveries in a virgin territory. He generously offered to pay for the costs of an entire expedition: thus was born the "Thayer Expedition to Brazil." Needless to say, Agassiz's enthusiasm revived overnight: he could now fulfill his dream of directing a scientific expedition to an exotic land, following the footsteps of Alexander von Humboldt, Alfred Russel Wallace and Henry W. Bates.

In agreement with Agassiz's philosophy at that time, the expedition would also have a strong educational and social character. He took along his wife and six students of Harvard, including Stephen V.R. Thayer, son of the patron of the expedition. Agassiz and his wife would write popular accounts on all aspects of the expedition, he himself would lecture on natural history, train his students and naturally help his assistants in collecting specimens. These assistants were: John Gould Anthony, conchologist; Orestes St. John, paleontologist and Charles Frederick Hartt, geologist.

Cooperation came from all scientific and diplomatic sources; the Pacific Mail Steamship Company placed the steamship "Colorado" at Agassiz's disposal. The expedition left New York on April 1, 1865, and returned August 6, 1866 with a collection of natural history samples and documents reaching 80.000, certainly a record. The expedition worked in small groups, each responsible for the study of a

particular area. The activity was concentrated for the first three months around Rio de Janeiro and the rest of the time was spent in the Amazon Valley.

The reception in Brazil was enthusiastic and the Emperor Dom Pedro II provided complete physical support to the expedition, appointing also major João-Martino da Silva Coutinho as a permanent guide to Agassiz. A lasting friendship developed between the Emperor and Agassiz and it is generally assumed that one of the results of their discussions was the Emperor's decision to open the Amazon River to international commerce in 1867. [37] Agassiz lectured to elite audiences about his special creationism and even introduced the Emperor himself to natural history.

The results of the Thayer Expedition were first published in three articles written by Agassiz and his wife in the *Atlantic Monthly*. The first entitled "An Amazonian Picnic" [38] is a delightful account of the folkloric side of the expedition, the people, the jungle, the collecting of samples and the travelling conditions. The second and third articles both entitled "Physical History of the Valley of the Amazons, I and II" [39] contain the account of the discovery of a Pleistocene continental glaciation in the Amazon Valley. These geological observations will be repeated in Chapter XIII "Physical History of the Amazons" of the attractive volume *A Journey in Brazil* [40] published in 1868 by Agassiz and his wife after the expedition. The same data are also reproduced in the *Geological Sketches*, 2nd series. [41] By combining these two major accounts it is possible to analyse the nature and the significance of Agassiz's alleged discoveries of evidence for a Pleistocene glaciation extending from Rio de Janeiro to the Amazon. During my visits to both places I have added some personal investigations.

Agassiz begins his contribution as follows:

> To-day I am led to add a new chapter to that strange history (the glacial phenomena), taken from the Southern hemisphere and even from the tropics themselves.
>
> I am prepared to find that the statement of this new phase of the glacial period will awaken among my scientific colleagues an opposition even more violent than that by which the first announcement of my views on this subject was met. I am, however, willing to bide my time; feeling sure that, as the theory of the ancient extension of glaciers in Europe has gradually come to be accepted by geologists, so will the existence of like phenomena, both in North and South America, during the same epoch, be recognized sooner or later as part of a great series of physical events extending over the whole globe... If the geological winter existed at all, it must have been cosmic... I came to South America, expecting to find in the tropical regions new evidences of a bygone glacial period, though, of course, under different aspects. [42]

Upon his arrival at Rio de Janeiro, Agassiz's attention was immediately attracted by "a very peculiar formation consisting of ochraceous, highly ferruginous

sandy clay," [43] extending all over the province of Rio de Janeiro and in the adjacent province of Minas Gerais. He found that: "It rested everywhere upon undulating surfaces of the solid rocks in place, was almost destitute of stratification, and contained a variety of pebbles and boulders. These pebbles were chiefly quartz, sometimes scattered indiscriminately throughout the deposit, sometimes lying in a seam between it and the rock below; while the boulders were either sunk in its mass or resting loose on the surface." [44]

In the Tijuca area, a few miles out of the city of Rio de Janeiro, near Bennett's Hotel, Agassiz saw: "... a great number of erratic boulders, having no connection whatever with the rock in place, and also a bluff of this superficial deposit studded with boulders, resting above the partially stratified metamorphic rock... There can be no doubt, in the mind of any one familiar with similar facts observed in other parts of the world, that this is one of the many forms of drift connected with glacial action." [45]

This definite interpretation of the red superficial layer as drift is however followed by a serious note of caution:

> It is true that the extensive decomposition of the underlying rock, penetrating sometimes to a considerable depth, makes it often difficult to distinguish between it and the drift; and the problem is made still more puzzling by the fact that the surface of the drift, when baked by exposure to the hot sun, often assumes the appearance of decomposed rock, so that great care is required for a correct interpretation of the facts. A little practice, however, trains the eye to read these appearances aright, and I may say that I have learned to recognize everywhere the limit between the two formations. There is indeed, one safe guide, namely the undulating line, reminding one of *roches moutonnées*, and marking the irregular surface of the rock on which the drift was accumulated; whatever modifications the one or the other may have undergone, this line seems never to disappear." [46]

Agassiz also mentions the confusing results of the disintegration of the rocks forming loose fragments which simulate erratic blocks but which are in fact only detached masses of the rock in place, but he thinks that a careful study shows their *in situ* character.

The alleged discovery of erratic boulders by Agassiz is expressed with great enthusiasm in a letter to his friend Professor Benjamin Peirce of Harvard University, dated May 27, 1865:

> Yesterday was one of the happiest days of my life, and I want to share it with you. Here I am at Tijuca, a cluster of hills, about eighteen hundred feet high and some seven or eight miles from Rio, in a charming cottage-like hotel, from the terrace of which you see a drift hill with innumerable erratic boulders, as characteristic as any I have ever seen in New England... I have not yet traced

> the boulders to their origin; but the majority consist of a kind of greenstone composed of equal amounts of a greenish black hornblende and feldspar... But you see that I need not go to the Andes to find erratics, though it may be necessary for me to go, in order to trace the evidence of glacier action in the accumulation of this drift; for you will notice that I have only given you the evidence of extensive accumulations of drift similar in its characteristics to Northern drift. But I have not yet seen a trace of glacial action properly speaking, if polished surfaces and scratches are especially to be considered as such. [47]

Agassiz is apparently impressed by the widespread occurence of this sheet of drift and by its fertility which he attributed to the great variety of chemical elements present in it as well as to the kneading process it has undergone beneath the gigantic ice plough. His coworkers explored other areas, such as the province of Espírito Santo, the valleys of the Rio Doce, Rio Mucurí, Rio San Francisco and of Piauí, finding everywhere the same cover of red unstratified clay, with pebbles and occasional boulders resting on the rock in place. In general, erratic boulders appear to become less abundant toward the Amazon basin and the red layer begins to show occasional signs of stratification. These variations will be accounted later on by Agassiz by a difference in time and in conditions of deposition between the North and the South of Brazil.

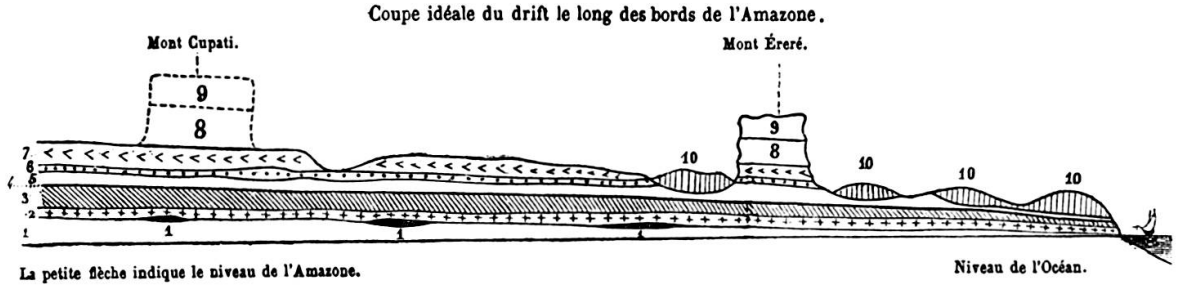


FIG. 2. — Ideal section of the "Pleistocene Amazonian drift" by L. Agassiz and J. M. da Silva Coutinho (1868, *Bull. Soc. Géol. France*).

Lower Formation
1. Coarse sandstone and sand
2. Plastic variegated clay
3. Finely bedded clay with plant remains
4. Very hard crust of sandy clay

Middle Formation
5. Regularly stratified to massive red sandstone
6. Vuggy red sandstone with irregular pockets of clay

7-9. Red sandstones with torrential stratification

Upper Formation
10. Reddish to brown, massive sandy clay with pebbles and erratic boulders

Before letting the reader completely astray, it is imperative to state that Agassiz was not looking at drift or erratic boulders, actually he was interpreting as such the widespread and thick residual layer of lateritic soil forming today all over Brazil. To

it are associated numerous boulders due to the spheroidal exfoliation of gneisses, granites and basic intrusions forming the Precambrian terrane around Rio de Janeiro, a process spectacularly demonstrated by the conical mountains of the Bay of Rio. It is true indeed that the real origin of the boulders and the associated clays is often obscured by creep and landsliding which throw the whole mass into a confusion closely resembling glacial boulder-clays. Furthermore, the so-called sections of *roches moutonnées* have no preferred orientation of their steeper side and simply represent the surface separating the less-altered bedrock from its lateritic cover. I have noticed and believe that it must be recognized in all fairness to Agassiz that a visit to the Tijuca area and particularly to the place called La Furnas with its deep canyons strewn with enormous boulders certainly suggests, at first glance, glaciated valleys of the Alps. However, a closer observation reveals the unmistakable effect of large-scale exfoliation and spheroidal weathering of igneous and metamorphic rocks. [48]

In the Amazon valley, Agassiz describes three superficial formations which he considers to extend throughout the basin, forming a series of flat-topped hills particularly in the regions of Almeirím, Obidos, Monte Alegre and Santarém (fig. 2). The lower formation consists of sandstones, sands and variegated clays containing plant remains. The middle formation is represented by irregularly stratified sandstones and sands, highly ferruginous with pockets of clay. The uppermost deposits rest unconformably on the middle ones and are essentially the same as the Rio drift, namely a reddish to brown clay, sandy and with scattered pebbles. On the northern side of the Serra of Ereré the deposit contains according to Agassiz: "... the only genuine erratic boulders I have seen in the whole length of the Amazonian Valley, from Pará to the frontier of Peru... the boulders of Ereré are entirely distinct from the rock of the serra, and consist of masses of compact hornblende." [49]

There seems to be no doubt in the mind of Agassiz that all these deposits belong to the Ice-Age and that the valley of the Amazon had its glaciers flowing down into it from the accumulations of snow in the Cordilleras and swollen laterally by tributary glaciers descending from the tablelands of Guiana and Brazil. He wonders however about the absence of furrows, striae and polished surfaces, so characteristic of the bedrock over which glaciers moved, and in that respect he says:

> Not a trace of them; for the simple reason that there is not a natural rock surface to be found throughout the whole Amazonian Valley. The rocks themselves are of so friable a nature, and the decomposition caused by the warm torrential rains and by exposure to the burning sun so great and unceasing, that it is hopeless to look for marks which in colder climates and on harder substances are preserved through ages unchanged. With the exception of the rounded surfaces so well known in Switzerland as the *roches moutonnées*, which may be seen in many localities, and the boulders of Ereré, the direct traces of glaciers as seen in other countries are wanting here. I am, indeed, quite willing to admit,

that, from the nature of the circumstances, I have not here the positive evidence which had guided me in my previous glacial investigations." [50]

Nevertheless, Agassiz proceeds with the glacial interpretation of the three superficial deposits of the Amazon valley. The lower and the middle were formed in a huge freshwater lake extending under the ice-sheet which originated from the Andes and extended to the mouth of the river where a high frontal moraine was located. Gradual destruction of this moraine led to the draining of the lake and the deposition of the uppermost deposit or red clay, similar to the Rio drift and the diabase blocks of Ereré are erratics rafted by icebergs during the final phase of melting of the glacier. [51]

Agassiz's enthusiasm appeared again boundless: while standing on the rim of the Serra of Ereré and looking southward across the Valley of the Amazon, he was led to write as follows: "... panoramas from the Swiss mountains came up to my memory, and I fancied standing on the Alps, looking across the plain of Switzerland, instead of the bed of the Amazons, the distant line of the Santarém hills on the southern bank of the river and lower than the northern chain representing the Jura range." [52] Agassiz's interpretation rested largely on the alleged existence of a huge frontal moraine extending across the mouth of the Amazon. The fact that no traces of it have been left is explained by his assumption that the Amazon valley extended originally much farther to the east and that intense marine coastal erosion had not only carried away the gigantic frontal moraine but also the very ground on which it stood. [53]

The region of the Monte Alegre dome where Agassiz made most of his observations is fairly complex in a structural point of view, and led him to confuse several formations. Today his lower set of beds corresponds to the so-called Alter do Chão Formation, the fluvial-lacustrine-continental episode of terminal filling of the Amazon Basin, ranging in age from Early Cenomanian to Miocene—Pliocene on the basis of palynological data. The occurrence in it of fossil leaves has been demonstrated and the locality described by Agassiz is the Serra Paitúna located immediately south of the Serra of Ereré. His middle deposit is, because of structural complications, a Mississippian coarse cross-bedded and silicified sandstone called the Faro Formation. (Viséan-Tournaisian). This is the only known outcrop of Faro in the Middle Amazon Basin which is usually encountered in sub-surface in the central part of the basin (M.V. Caputo, PETROBRÁS, unpublished data). Agassiz's third and uppermost deposit is naturally lateritic soil. The alleged erratic blocks of the Serra of Ereré are boulders due to the spheroidal weathering of Mesozoic diabase intrusions which crop out within the shales of the Curuá Formation (Devonian) forming the core of the structure and visible immediately north of the Serra of Ereré.

Upon leaving the Amazonian valley, Agassiz visited the province of Ceará, extending east of the Amazon, in order to find proofs of the former existence of local glaciers in the serras of this province and particularly traces of the southern lateral

moraine marking the limit of the mass of ice which filled the Amazonian basin during the glacial period. [54] He did find all what he was looking for and concluded his description by the following comparison:

> I may say, that in the whole valley of Hasli there are no accumulations of morainic materials more characteristic than those I have found here,—not even about the Kirchet; neither are there any remains of the kind more striking about the valleys of Mount Desert in Maine, where the glacial phenomena are so remarkable, nor in the valleys of Lough Fine, Lough Augh, and Lough Long in Scotland, where the traces of ancient glaciers are so distinct. In none of these localities are the glacial phenomena more legible than in the Serra of Aratanha. I hope that before long some members of the Alpine Club, thoroughly familiar with the glaciers of the Old World, not only in their present, but also in their past condition, will come to these mountains of Ceará and trace the outlines of their former glaciers more extensively than it has been possible for me to do in this short journey. [55]

Agassiz's feelings at the end of his Brazilian trip can be adequately summarized by an excerpt of a letter he wrote to his mother, dated at sea, July 7, 1866: "I have found traces of glaciers under this burning sky; a proof that our earth has undergone changes of temperature more considerable than even our most advanced glacialists have dared to suggest. Imagine, if you can, floating ice under the equator, such as now exists on the coasts of Greenland, and you will probably have an approximate idea of the aspect of the Atlantic Ocean at that epoch." [56]

Less than a week after his return to Boston, Agassiz visited Washington and on August 12, 1866 read a paper entitled "Traces of glaciers under the tropics" at the annual meeting of the National Academy of Sciences. [57] The paper was not published but its content was described in a letter of Asa Gray to Charles Darwin, dated August 27, 1866, preserved in the Historic Letter File, Gray Herbarium. [58] E. Lurie comments as follows:

> This remarkable address advanced hypotheses which were as challenging as those of his glacial theory of 1837. Glacial action, he reported, had covered great areas of Brazil. He noted that he had been previously convinced by his geological explorations that glaciers had existed in North America; his experience among Brazilian land formations and mountain chains now yielded similar results for South America. Agassiz concluded that the flora and the fauna of America had been created anew after the glacial ice had receded and that no genetic relationship was possible between animals and plants which had lived prior to and after the glacial epoch. Here again was undeniable evidence of the mistaken conceptions of evolutionists. [59]

A series of lectures before the Lowell Institute in September and October 1866 was also devoted to the evidence of glaciation in South America and it was repeated in New York.

Agassiz did not publish all the results of his Brazilian expedition in semi-popular magazines. There exist three accounts of his discoveries which appeared in scientific periodicals, but outside the United States. The first two are in the form of letters, respectively to Jules Marcou [60] and to Elie de Beaumont. [61]

The third is a joint paper with Martino da Silva Coutinho [62] with an introduction by J. Marcou wherein he compares Agassiz's statement of a glacial period of 1837 with the Amazonian discoveries and says: "In his voyage to Brazil and the Amazons, M. Agassiz has just added a new chapter to the extraordinary history of glacial phenomena, a chapter even more extraordinary, if at all possible, than the phenomenon itself, since M. Agassiz travelled to find it not only to the southern hemisphere, but to the tropics themselves..." [63] Marcou also mentions the fact that before Agassiz's arrival in Brazil, an observer had noticed for many years, during his walks in the vicinity of Rio de Janeiro, numerous erratic boulders which recalled to him in all respects the descriptions of the same phenomenon of Europe and North America. Not sure of himself, he had related his views to M. Agassiz asking him to come and assess the facts in the field. This observer is supposed to have been the Emperor of Brazil himself, Dom Petro II. This is certainly a little-known facet of the history of the Brazilian glaciation.

The joint paper by Agassiz and Coutinho ends with the following conclusions by Jules Marcou: "This interpretation, presented by an observer so skillful and so thorough and having so much experience as M. Agassiz, will be accepted by all geologists as marking a new and fundamental phase of the Ice-Age theory." [64]

Naturally English and American naturalists were amazed, if not dismayed upon hearing of Agassiz's alleged discoveries. Their reaction was particularly strong since the careful investigations in the Amazon valley undertaken by Henry W. Bates and Alfred Russel Wallace over many years had never led to the discovery of any sign of glaciation whatsoever, and many other naturalists who had visited the area had reached similar results. Agassiz, after less than a year in the field, contradicted all existing knowledge on the basis of scanty and doubtful observations. Sir Charles Lyell aptly summarized the general reaction of the scientific community in a letter to Charles Bunbury, dated September 3, 1866: [65]

> Agassiz has written an interesting paper on the "Geology of the Amazons," but I regret to say he has gone wild about glaciers, and has actually announced his opinion that the whole of the great valley, down to its mouth in lat. O, was filled with ice, and damned up by a moraine since destroyed by the sea, by means of which he accounts for freshwater deposits such as we find in the valleys of the Mississippi and Rhine. He does not pretend to have met with a single glaciated

> pebble or polished and striated rock *in situ*, and only two or three far-transported blocks, and those not glaciated. As to the annihilation during the cold of all tropical and extra-tropical plants and animals, that would give no trouble to one who can create without scruple not only any number of species at once, but all the separate individuals of a species capable of being supported at any time in their alloted geographical province.

This assessment, correct in all respects in the light of our present knowledge, was written by Lyell when he himself had not yet accepted the ideas of Darwin. It confirms the speculation that Agassiz was determined to oppose Darwinian evolution at all costs, even without observation facts, in what appears now as a desperate attempt to regain scientific stature by means of a major discovery comparable to his stroke of genius of 1837 in the Alps. A corroborative evidence is given by his wife who wrote the following comments on his work in Brazil: [66]"... the character of the soil and other geological features confirmed him in his preconceived belief that the glacial period could not have been less than cosmic in its influence. He was satisfied that the tropical, as well as the temperate and arctic regions had been, although in a less degree, fashioned by ice."

Agassiz's work in Brazil represents the last effort of his dogmatic opposition to the theory of evolution. Subsequently he would try to analyse Darwinism with as much objectivity as he could muster as shown in his posthumous paper "Evolution and permanence of type." [67] He also had become acutely aware that natural history, in particular paleontology, was making rapid progress under the impetus given by the evolution theory and by the works of some of his own students. He tried to get involved again in original investigation. When, in the summer of 1868, Samuel Hooper, one of his old friends and trustee of the museum, offered to undertake the costs of an exploration party which would observe the progress of the Union Pacific and explore parts of the Rocky Mountains, Agassiz eagerly accepted to be the leader of such a team. This trip to the West allowed Agassiz to find significant evidence of glacial phenomena over broad areas of the High Plains and in the Rocky Mountains, but he did not publish his findings.

The embarassing situation which had arisen from Agassiz's concept of an Amazonian glaciation was alleviated by his participation in the Hassler Cruise of 1871 under the auspices of the U.S. Coast and Geodetic Survey. This new expedition circumnavigated South America from New York to San Francisco and gave Agassiz the opportunity to study the glacial phenomena in the southern part of South America, previously described by Darwin. [68] A study of his short publications, [69, 70, 71] of his wife's articles in the *Atlantic Monthly* [72,73] and of his letters, [74] clearly shows that he confirmed Darwin's observations, namely that during the Pleistocene, glaciers extended from the Straits of Magellan to as far north as 37° latitude S, in a pattern essentially symmetrical with the ice-sheet of the northern hemisphere.

Agassiz avoided any formal retractation of his concept of an Amazonian glaciation, he simply did not mention the subject again. [75] When commenting on the fact that he had traced direct evidence of glaciation from Montevideo on the Atlantic to Talcahuano on the Pacific coast, he wrote in 1872: "Think of it! A characteristic surface indicating glaciation action in latitude 37° S at the level of the sea!" [76] Obviously, Agassiz's statement on what he considers the northernmost erratics and glaciated surfaces reported in the southern hemisphere suggests that he implicitly considered as invalid his previous evidences of glaciation in equatorial Brazil. Such an attitude can certainly be accepted as a form of retractation coming from a man who contributed so much and for so long to the progress of the biological and geological sciences.

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[76] See reference 70.

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