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H.-B. DE SAUSSURE : JAMES HUTTON'S OBSESSION

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ABSTRACT

H.-B. de Saussure : James Hutton's obsession. – James Hutton's last *Theory of the Earth* (1795) has the unusual feature of being bilingual, with at least one fourth of its two volumes (1187 pages) in quoted French. Hutton had chosen these citations from the works of H.-B. de Saussure and other French-speaking naturalists. His previous Theory of 1788, mainly based on his own geological observations in Scotland, and thus lacking the knowledge of other European areas, had been harshly criticized as being regional in scope instead of universal. Hutton was therefore anxious to analyze other geological settings described in published works, in particular the Alps, which had recently become famous by Saussure's *Voyages dans les Alpes...* (1779, 1786). Hutton, although using Saussure as his most reliable source, was actually quoting facts and interpretations by a Neptunistic geologist to document his new Plutonistic theory. This provided a most challenging comparison between two diametrically opposed points of view, as well as some insight into Hutton's almost obsessive wish to interpret geological facts without having seen them. This important contribution to the history of geology has remained little known because of the language barrier. It is presented in this work for the first time together with the English translation of Saussure's quoted text.

Key-words : Neptunism, Plutonism, theory of the earth, granite, Alps, Mont-Blanc, Monte-Rosa, Salève.

RÉSUMÉ

La dernière *Theory of the Earth* (1795) de James Hutton possède le caractère inhabituel d'être bilingue avec au moins un quart de ses deux volumes (1187 pages) représenté par de longues citations en français provenant des travaux de H.-B. de Saussure et d'autres naturalistes francophones. Sa théorie précédente de 1788, basée principalement sur ses propres observations en Ecosse, et ne tenant pas compte des connaissances d'autres régions européennes, avait été fortement critiquée comme étant de nature régionale et non pas globale. Par conséquent, Hutton était très anxieux d'analyser, par personne interposée, d'autres situations géologiques, en particulier les Alpes récemment devenues fameuses à la suite des *Voyages dans les Alpes...*(1779, 1786) de Saussure. Hutton, tout en considérant de Saussure comme sa source la plus

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fiable, se trouvait ainsi dans la situation d'utiliser les faits et les interprétations d'un géologue neptuniste pour démontrer sa nouvelle théorie plutoniste. Cette situation donne lieu à une comparaison provocatrice entre deux points de vue diamétralement opposés et à un aperçu sur l'obsession de Hutton d'interpréter des faits géologiques sans les avoir vus lui-même. La barrière linguistique a fait que cette importante comparaison pour l'histoire de la géologie est restée peu connue. Elle est présentée dans ce travail pour la première fois avec la traduction en anglais des citations du texte de Saussure.

Mots-clés: Neptunisme, Plutonisme, théorie de la terre, granite, Alpes, Mont-Blanc, Monte-Rosa, Salève.

INTRODUCTION

This paper presents a comparative study of the geological works by James Hutton and Horace-Bénédict de Saussure. I found that, with the exception of Playfair (1802), the two naturalists have never been compared before. The reason for this might be that few historians of geology have actually read all of Hutton's last work (1795). Indeed, the lengthy descriptions and citations in French of works by Saussure and other European naturalists may have discouraged many a reader. For example, Vol. I of 620 pages, has about 80 pages of citations; Vol. II. of 567 pages, has 277, and Vol. III of 267 pages, has 41. These facts alone can easily cause a language barrier. In fact, many historians of today prefer to peruse Playfair's *Illustrations...* or Hutton's earlier and shorter *Theory of the Earth...* (1788).

Since Hutton repeatedly mentioned Saussure as his most reliable source, this paper will give a translation of all French citations from Saussure's first two volumes in Hutton's Vol. I and II (1795), as well as from his manuscripts, published under the title of Vol. III (Geikie, ed., 1899; Dean, ed., 1997), thus trying to lift at least some of the difficulties for the modern reader in his understanding of Hutton's last works.

During these translations, I found, unsuspectedly, the ideas of the two geologists side by side, thus providing a most challenging insight into the different ways of interpreting facts by Hutton and Saussure. Their ideas are indeed very often diametrically opposed and therefore all the more interesting for this comparison.

Methods and techniques

I translated into English Saussure's French texts cited by Hutton in his last *Theory of the Earth* (1795) and in Volume III, after careful comparison with Saussure's original French text in *Voyages dans les Alpes*...Vols. I and II, (1779, 1786). Small typos in Hutton's French were corrected without mentioning them whereas critical errors were referred to in the translation within square brackets. Ellipses were used before or after Hutton's citations if the beginning or the end of a paragraph, or several paragraphs by Saussure, are missing. To distinguish Hutton's words from those of Saussure, the translation of Saussure is *left-indented* and includes, if necessary, explanations by the

translator in square brackets. French expressions or spelling of localities, rivers, and mountains, mostly modernized, are in italics. The following abbreviations were used: for Hutton's vols. I and II for example: [H. I. 333] and for Saussure's translated text [S. I. §. 100, p. or pp....]. Saussure's paragraphs were given before the pages of the edition in 4° because an edition in 8° of *Voyages...* exists with different pagination but same paragraph numbering. References to Hutton are always given at the beginning of the citation, while short references to Saussure are at the end of the citation. If the latter are long, they are, if possible, placed at the beginning too.

VOLUME I

This volume explains mostly Hutton's own ideas with fewer references to Saussure than in vols. II and III. Struggling to explain consolidation of strata, Hutton first refers to Saussure's ideas on the marine origin of calcareous bodies and then to processes of crystallization.

On crystallization processes in limestones

In Vol. I. Hutton points out [H. I. 23-24] that

"There are few beds of marble or limestone, in which may not be found some of those objects which indicate the marine origin of the mass. If, for example, in a mass of marble, taken from a quarry upon the top of the Alps or Andes*, there shall be found one cockle-shell, or piece of coral, it must be concluded, that this bed of stone had been originally formed at the bottom of the sea..."

He cites Saussure's text in a footnote *:

> * "This summit [to the east of the Lake of Flaine, on a mountain called *le haut de Veron*, or *la Croix de Fer*] reaching 984 toises above our lake [Lake Geneva], and therefore 1172 toises above sea level, is noteworthy because it shows fragments of petrified oysters....This mountain is dominated by a steep rocky cliff which, though not inaccessible, is nevertheless very difficult to climb. It seems to consist almost entirely of petrified shells enclosed in a limestone or coarse blackish marble. The fragments which become loose, and are found at the *Croix de Fer*, are filled with *turbinites* of different species." [S. I. §. 469, pp. 393-394].

Hutton concludes: [H. I. 24]

"We thus shall find the greatest part of the calcareous masses upon this globe to have originated from marine calcareous bodies..." He adds:

"In those calcareous strata which are evidently of marine origin, there are many parts that are of sparry structure, that is to say, the original texture of those beds, in such [H. I. 25] places, has been dissolved, and a new structure has been assumed, which is peculiar to a certain state of the calcareous earth. This change is produced by crystallization, in consequence of a previous state of fluidity... A body, whose external

form has been modified by this process, is called a *crystal*, one whose internal arrangement of parts is determined by it, is said to be of a *sparry structure*; and this is known from its fracture."

He then points to masses, only partly crystallized into spar and in part still retaining their original form, which, he says, proves their marine origin, referring in a footnote to Saussure's description of the marble of Aigle [H. I. 26]:

> "The polished tables of this marble frequently show sea shells, mainly striated pecten and very beautiful madrepores. All these marine bodies have taken on the aspect and the grain of marble, the shell being hardly recognizable in its original shape..."
> No pagination was given by Hutton, it is: [S. II. §. 1092, p. 541].

After mentioning crystallization in agates with their cavity filled in a fluid state in order to crystallize, Hutton turns to Saussure's granite, saying that [H. I. 90-91] "In granite, these cavities are commonly lined with crystals corresponding to the constituent substances of the stone, viz. quartz, feldspar, and mica or chalk. M. de Saussure... says":

> "Large masses of calcareous spar [calcite] are frequently found crystallized in caves where rock crystal is formed; although these caves are enclosed in the center of mountains of pure granite [*granit vif*] and no limestones are found above these mountains." [S. II. §. 722, p.131]

Hutton corrects Saussure:

"So accurate an observer, and so complete a naturalist, must have observed how the extraneous substance had been introduced into this cavity, had they not been formed together the cavity and limestone crystals. That M. de Saussure perceived no means for that introduction, will appear from what immediately follows in that paragraph."

> "Were these rocks [Saussure said "these limestones"] destroyed or is this spar merely the product of a secretion of limestone parts which are known to be scattered among the various constituents of granite?" [S. II. §. 722, pp. 131-132]

Hutton interjects [H. I. 91]:

"Had M. de Saussure allowed himself to suppose all those substances in fusion, of which there cannot be a doubt, he would soon have resolved both this difficulty, and also that of finding molybdena [molybdenite] crystallized along with feldspar, in a cavity of this kind. § 718."

Hutton's criticism is quite subtle because he seemingly neither wants to correct nor confirm Saussure's attitude of doubt in these matters. He mentions merely Saussure's account of *Molybdena granite* under § 718, but does not transcribe it. Saussure's explanation is in fact completely opposite to Hutton's ideas and is worth a translation.

Under the marginal heading of *Molybdena in granite*, Saussure said: [S. II. §. 718, pp. 128-129]

"This reflection would lead me to believe that somewhere, in the mountains of Chamonix, true molybdena occurs, a very rare mineral, that was well distinguished by the immortal *Bergman* from *plombagine* or common lead. The matrix in which the molybdena was found at Chamonix is even more remarkable than the mineral itself. To enlarge the road near Argentière, leading to Valorsine, blocks of granite were blown up to clear the road. *François Paccard*, one of the guides of Chamonix, saw at the surface of one of these blocks a shiny mineral which he detached and brought to me. When he said that he had found it in a block of granite, I could not believe it. Fortunately, there was enough left on the block to convince me. Nevertheless, I could not affirm whether this substance was enclosed in the center of the block itself; the nest which held the mineral was at the edge of one of the former faces of the block so that there could well have been an opening through which the waters could have carried the material of the molybdena inside a cavity which existed before in the granite. The molybdena occurred there crystallized or at least with its characteristic shape of sheets radiating around different centers. This substance was surrounded by yellowish feldspar which also seemed to have penetrated and filled this cavity by infiltration. In fact, it is there more abundant than in the rest of the granite, its crystallization is less irregular and its texture less tight, characters typical of bodies formed by infiltration."

Consolidation of strata: by water or heat ?

Hutton proposes the following: [H. I. 111] :

"... if strata have been consolidated by means of aqueous solution, these masses should be found precisely in the same state as when they were originally deposited from the water. The perpendicular section of those masses might shew the compression of the bodies included in them, or of which they are composed; but the horizontal section could not contain any separation of the parts of the stratum from one another.

If again, strata have been consolidated by means of heat, acting in such a manner as to soften their substance, then, in cooling, they must have formed rents or separations of their substance, by the unequal degrees of contraction which the contiguous strata may have suffered. Here is a most decisive mark by which the present question must be determined.

There is not in nature any appearance more distinct than this of the perpendicular fissures and separations in strata. These are generally known to workmen by the terms of veins or backs and cutters; and there is no consolidated stratum that wants these appearances. Here is therefore, a clear decision of the [H. I. 112] question, Whether it has been by means of heat, or by means of aqueous solution, that collections of loose

bodies at the bottom of the sea have been consolidated into the hardest rocks and most perfect marbles*."

A footnote in small print by Hutton says:

* "This subject is extremely interesting, both to the theory of the earth, and to the science of the mining art. I will now illustrate that theory, with an authority which I received after giving this dissertation to the Royal Society. It is in the second volume of M. de Saussure's *Voyages dans les Alpes*. Here I find proper examples for illustrating that subject of mineralogy...

The first example is a marble in the Alps *(Voyages dans les Alpes*. tom. 2, page 271."

Hutton citation of Saussure follows:

> [H. I. 112] :" The matrix of this breccia is now white, now gray, and the enclosed fragments are either white, gray, or reddish-brown, and almost always of a color different from that of the matrix which holds the fragments together. They are all limestones, at least those that I could observe. What is most interesting is that these fragments [Hutton omitted here: 'had a lenticular flattened shape'], are all aligned in the direction of the schistosity of the rock. When observing them we might say that these fragments were all compressed and crushed in the same direction. The same breccia is interspersed with mica, especially in the interstices of the layers and between the fragments of the matrix [H. I. 113] which holds them together. But there is no visible mica in the fragments themselves. In these breccias are also infiltrations of quartz. The rock is cut by frequent fissures, perpendicular to the layers. It is clear that these fissures were formed during uneven sinking of the layers, and not by spontaneous contraction because the pieces or foreign fragments are all divided and clearly cut by these fissures whereas in natural divisions of layers, such fragments are whole and jot out at the surface. The quartz nodules and the various crystals inside schistose rocks present the same phenomenon, and we can draw the same conclusion that they are cut in pieces by the fissures and remain whole in the separations of layers." [S. II. §. 841, pp. 271-272]

Hutton is here referring to the *Col de la Seigne* crossing a mountain that leans, on the one hand, against the chain of the Mont-Blanc and on the other, against the first "secondary chains" of Italy. He omits however, the following passage given by Saussure immediately after the above paragraph. It sounds quite different :

> [S. II. §. 841, p. 272]
> "Although at first sight, these flattened fragments led me to believe in a compression, as mentioned above. However I cannot accept it because there is no further trace of such a compression. I would rather believe that these fragments were part of very thin layers which were abraded under water by rolling and

erosion and later on, when they were successively carried along and deposited by the waters, took on a horizontal position according to gravity. Finally, elements of limestone, forming the bottom of the breccia, were deposited at the same time, or in alternations, like the breccias which encased them in that position."

Skipping many pages in Saussure's work, Hutton, then quotes Saussure again on the same subject [H. I. 113]:

"Further down we pass between two layers of the same breccias between which are intercalated layers of black slate and micaceous schistose sandstone whose inclination is identical.

The same breccias occur again toward the bottom of the descent, at the foot of limestone pyramids which I mentioned above. In 1774, I found very nice rock crystals which had formed in the fissures of this breccia. There was even a mixture of quartz and [H. I. 114] mica enclosed in some of the fissures. Therefore, it is a rock that resembles primitives ones, but of a later origin than limestone. And what system could not convince us that nature may produce again what it did in the past !" [S. II. §. 850, p. 280]

Hutton corrects [H. I. 114] Saussure saying that the so-called breccia is, in fact, "a pudding stone, with veins or contractions of the mass. He [Saussure] does not seem to understand these as consequences of the consolidation of those strata; this, however, is the only light in which these appearances may be explained, when those bodies are thus divided without any other separation in the mass.

The second example is found in the vertical strata of those mountains through which the Rhône has made its way in running from the great valley of the *Vallais* towards de lake of Geneva. (Chapter xlviii)." It reads:

[H. I. 114]: "It is some kind of petrosilex, gray, hard, and ringing, somewhat transparent, which splits into perfectly flat and regular thin sheets. The sheets, or rather the layers, run at 35 degrees NE, rising westward at an angle of 80 degrees. These layers are cut by fissures which are perpendicular both to the layers and to the horizon. This rock is extracted for the same uses as slates but it is much harder and long-lasting because it is hard and less susceptible to weathering by water and air." [S. II, §. 1046, pp. 497-498]

"§. 1047. The nature of these petrosilex changes gradually, incorporating parts of feldspars into the interstices of their sheets. They thus acquire the appearance of a quartzose and micaceous schistose rock (*quartzum fornacum W.*). However, this aspect is deceiving because not even an atom of quartz can be found, and all the white parts which produce fire when rubbed against steel are feldspars whereas the gray scaly parts are not mica but thin sheets of petrosilex which I previously mentioned." [S. II. §. 1047, pp. 497-499]

Hutton [H. I. 115] disagrees and calls these rocks "petuntze strata or porcelain stone, that is, strata formed by the deposit of such materials as might come from the *detritus* of granite, arranged at the bottom of the sea, and consolidated by heat in the mineral regions."

On the same subject, he refers again to Saussure [H. I. 115-116]:

> "§. 1048. This rock mixture [situated between Martigny and St. Maurice] continues until the outcrop is at some distance from the main road. There, it is cut vertically over a great area by large oblique fissures which are roughly parallel to each other. These fissures separate the mountain into large 50 to 60 feet [H. I. 116] thick slabs which, from a certain distance, resemble layers. But a closer look reveals, by the very texture of the foliated rock itself, that the real layers are at an angle with the horizon of 70 to 75 degrees and that these large divisions are real fissures through which a large number of successive layers are cut almost vertically to their planes. The masses of rocks in between these large fissures are further separated by other smaller fissures, most of them parallel to the large ones, others oblique to them. However, all are roughly perpendicular to the plane of the layers of which the mountain consists." [S. II. §. 1048, p. 499]

Hutton adds [H. I. 116]:

"Here is a distinct view of that which may be found to take place in all consolidated strata, whatever be the composition of the stratum, and it is this appearance which is here maintained to be a physical demonstration, that those strata had been consolidated by means of heat softening their materials."

Playfair who has tried to explain Hutton the best he could said about Hutton's consolidation: "Though Dr. Hutton has no where defined the meaning of the term consolidation, he has been scrupulously exact in using it constantly in the same sense. He understands by it, not merely the quality in a hard body by which its parts cohere together, but also that by which it fills up the space comprehended within its surface, being to sense without porosity, and impervious to air and moisture." The entire explanation extends from page 15 to 40 (Playfair,1802).

Hutton's attitude versus the alleged primitive mountains

Hutton states in Chapter IV [H. I. 311]:

"In the theory now given, the earth has been represented as a composition of different materials, which had existed in another form, and as the effect of natural operations" but none of the parts can be considered as original or primitive. However, other naturalists pretend "that there are certain primitive mountains in the earth, bodies which have had another origin than that of the general strata of the globe and subsequent masses; an origin, therefore, which cannot be considered as having been produced from natural operations..."

[H. I. 313] Hutton mentions that "M. de Saussure, who has examined this subject perhaps more than any other person, and who has had the very best opportunities for this purpose, says, that this composition may be found in all the different combinations which may be produced by every possible composition of 7 or 8 different kinds of stone (page 108, *Voyages...*) ."

Instead of refuting Saussure's belief in primitive mountains immediately, Hutton first mentions that:

[H. I. 314] "...it is certain that granite, or a species of the same kind of stone, is thus found stratified. It is the *granite feuilleté* of M. de Saussure, and if I mistake not, what is called *gneiss* by the Germans. We have it also in our north alpine country of Scotland; of this I have specimens, but have not seen it in its place." However, granite in masses, he adds, "have no right of priority over the schistus, its companion in the alpine countries, although M. de Saussure, [H. I. 315] whose authority I would revere, has given it for the following reason; that it is found the most centrical in the chains of high mountains, or in alpine countries." [see S. II. §. 919, p. 339]

Hutton argues :

"It may be proper to see the description of a calcareous alpine mountain. M. de Saussure gives us the following observations concerning a mountain of this kind in the middle of the Alps, where the water divides in running different ways towards the sea. It is in describing the passage of the *Col du Bonhomme* ..." [H. I. 321-322]

> "§. 759. On the right or west of these rocks, is a mountain of limestone, astonishing by the boldness with which it rises toward the sky its pointed and spiked pinnacles, cut in sharp angles like the high pinnacles of granite. This mountain however is certainly of limestone because I had a close look and found detached blocks on the road.
>
> [H. I. 322] This rock thus has the characteristics of the oldest limestones; its color is gray, the grain rather fine, and there is no vestige of organized bodies. Its layers are not very thick, but wavy, and frequently cut by fissures, parallel among each other and perpendicular to their plane. Among these fragments one finds also gray limestone breccias." [S. II, §. 759, p. 175]

Hutton wonders: [H. I. 333] "This mountain considered by itself, may perhaps afford no data by which a naturalist might read the circumstances of its origin. But, is a theory of the earth to be formed upon such a negative observation ? and is there any particular in this mountain, that may not be shown in others of which the origin is not in any degree doubtful ?"

[Hutton's opposition to Saussure's belief in primitive mountains is going to be repeated in much greater detail in volume III.]

Hutton's search for junctions

[H. I. 448] Looking for "junctions of the alpine with the level countries," he believes to have found them in the Val d'Aoste, near *Yvrée* where "M. Saussure describes such a stone as having been employed in building the triumphal arch erected in honor of Augustus."

> "§. 957...This arch, formerly covered by marble, is formed by large masses of a particular species of *poudingue* [conglomerate] or coarse-grained sandstone. It is an assemblage of mostly angular fragments of all kinds of primitive foliated rocks [*roches feuilletées*], quartzose, and micaceous, the largest of these fragments are smaller than a hazel nut. Most old buildings in the city of Aosta and its surroundings are built with this kind of material. The local inhabitants believe it to be an artificial mixture of rocks, but I have found them in place in the mountains north and above the road of Yvrée." [S. II. §. 957, p. 393]

[H.I. 449] Hutton concludes: "We may now come to this general conclusion, that in this example of horizontal and posterior strata placed upon the vertical *schisti*, which are prior in relation to the former, we obtain a further view into the natural history of this earth."

There are no further references in Vol. I to Saussure. The remaining chapters are treating petrification, the nature of mineral coal and coal strata occurring in Scotland.

Summary of discussion in Hutton's Vol. I.

In this first volume, Hutton agreed with Saussure only on the fact that layers of marble and limestone, including fossils, are of marine origin. However, the original structure of limestone had been later dissolved and had taken on a new sparry structure. This change was produced by crystallization due to a previous state of fluidity while consolidation had taken place. Foreign materials were introduced during cooling and contraction when the materials were soft. Visible rents and separations of their substance point to unequal contraction during the time of heat followed by cooling and consolidation. Another proof, vertical fissures and separations can be seen in strata everywhere. Hutton's last search for a junction between the alpine and the level country, as existing in Scotland, will be discussed in detail in Vol. III.

VOLUME II

In this volume, Hutton follows Saussure's many trips to the Salève, the Jura Mountain and the Alps, in the search of facts that he could not examine himself. He concentrates on Saussure's clear descriptions of the structure of mountains and their

layers in horizontal, vertical and folded positions. The amount of citations in Vol. II is much greater than in Vol. I and focuses, in particular, on the descriptions of the Alps and the Mont-Blanc. As in Vol I, he compares Saussure's initial theory with his own. Unfortunately, he could not read Vol. III and IV by Saussure, nor his many manuscripts, only recently studied in depth (Carozzi, A. V. 1998) where Saussure developed his final theory of horizontal thrusting.

Structure of limestone mountains: the Salève

In Chapter I, Hutton says :

[H. II. 6] "The first object now to be examined, in confirmation of the theory, is that change of posture and of shape which is so frequently found in mountainous countries, among the strata.... No person has had better opportunities of examining the structure of mountains than M. de Saussure, and nobody more capable of taking those comprehensive views that are so necessary for the proper execution of such a task. We shall therefore give some examples [H. II. 7] from this author, who has every where described nature with a fidelity which even inconsistency with his system could not warp...." Saussure's citation follows:

> [H. II. 7] "In some places, indeed almost everywhere, the layers descend straight from the summit of the mountain toward its foot: but above *Collonges-sous-Salève*, the rounded summit [*dos-d'âne*] shows layers which descend on both sides, that is, SE toward the Alps and NW toward our valley, with the difference that those descending toward the Alps reach the bottom whereas those facing us are cut vertically over a great height.
>
> These two slopes are not the only ones that are observed in the layers of the Salève: there is yet a third kind whose layers are raised toward the middle of the length of the mountain and descending from there toward its extremity. This slope, which on the Grand Salève is not very visible, becomes very clear on the Petit Salève where the layers are very steep even at its extremity. The [H. II. 8] last layers in the north, underneath Etrembières, descend toward the N-N-E at an angle of 40 or 50 degrees.
>
> In the course of this work, we shall see how limestone mountains have frequently this shape. [S. I. § 234, p. 180]
>
> § 235. Besides these large beds which build up the body of the mountain, and which are generally classified among horizontal layers, there are others with completely different inclination. They occur at the base of the Grand Salève on the side facing our valley. They are seen to be leaning against the lower sections of horizontal beds. [missing section: They are themselves either perpendicular to the horizon] or very inclined against the mountain. [S. I. §. 235, p. 180]

These layers rise in some places, for instance between Veyrier and Crevin, roughly to half the height of the Grand Salève. Those which touch the mountain immediately are most inclined. Some of them occur there in a vertical position, sometimes even tilted backward, and supported by the most exterior layers. Those are at an angle [H. II. 9] of 60 to 65 degrees. These layers are often very widespread, uninterrupted, and continuous over great distances. Their association forms a great thickness at the foot of the mountain. Nevertheless, they have been broken, and are even completely missing in some places. This very fact provides the opportunity to observe them well because if one is positioned in these intervals, their layers are seen laterally so that their edges and their entire structure can be clearly observed.

These layers can be noticed not only at the foot of the bare rocks of the Grand Salève, but also in that part of its slope which is covered by trees, for instance below the Croisette, because the path descending from this hamlet to the village of *Collonges-sous-Salève* crosses over inclined layers as those just described. [S. I. §. 235, pp.181-182]

§. 237. Following the foot of the mountain between the Coin [corner] and Crevin, we see reappear those vertical or very inclined layers which opposite the Coin were destroyed as mentioned above. These layers, when [H. II. 10] starting to crop out, are in great disarray. Nevertheless, they are very well recognizable and clearly rising against horizontal layers of the mountain.

While advancing further in the same direction, the same layers are seen to lose their vertical position and become almost horizontal. Their position changes even to the point that instead of leaning against the body of the Mont Salève, as they usually do, they now turn their back, rising against the lake and showing their escarpments to the other side. But little by little, the layers straighten up to form an angle of 83 to 84 degrees. Finally, above Crevin, they rise anew against the mountain as those I mentioned first.

At the foot of the Petit Salève, these layers are entirely lacking; at least I did not see any trace of them. It is possible that their summits were destroyed and that their bases remain hidden under the debris accumulated at the foot of the mountain." [S. I. §. 237, pp. 183-184]

Hutton explains [H. II. 11]: "Here we find strata, which had been originally formed at the bottom of the sea, by having transported materials deposited in horizontal beds, now raised from that place in which they had been formed, and variously broken, bent, and inclined from that horizontal plane in which they had been deposited. This is the view of things which is general in this earth, and of which this author describes so well the particulars."

Structure of limestone mountains : the Jura Mountains

From the above, it is obvious that Hutton has used only specific descriptions by Saussure that explained his own theory of uplifting. He then refers to Saussure's examination of the structure of the Jura Mountains.

[H. II. 11] "...we shall recognize that the first mountain-chain consists in its frontal or eastern flank of layers which rise leaning against the body of the chain itself while the same layers descend on the opposite side toward the valley of *Combe de Mijoux* to form the western face of the same chain. The general form of the layers of this chain resembles therefore a thatched roof which rises from the ground up to the gable and descends on the opposite side from the gable to the ground. The inner layers seem parallel to those outside [H. II. 12] so that all the layers of the mountain can be compared to a deck of cards folded into two along its length." [S. I. §. 332, pp. 270-271]

[H. II. 12] "§. 337. The chains forming the Jura, while becoming more distant from the high eastern line, loose gradually in altitude and continuity. The most western ones do not form, as the first, high and uninterrupted mountain-chains; they are hills still elongated, but isolated, or at least only connected by their bases.

§. 338. Their structure is not the same everywhere in the Jura. The most general primitive form however resembles that of the high chain, namely vaults consisting of and filled with concentric arches.

It is particularly between Pontarlier and Besançon that one meets hills which display that structure in a regular way. The main road [H. II. 13] crosses large valleys where the layers are horizontal; but these valleys are separated by chains of little elevation whose arched layers rise up to the top of the mountain and then descend on the opposite side. Others of the same form are also seen in the *Prévôté de Moutier Grand Val.*: "the *Birs* [river] crosses rocks showing the interior structure of mountains; there the layers form arches one above the other following the exterior shape of the mountain. *-Dict. Géog. de la Suisse, vol. 2, p. 150." (Dictionnaire Géographique...*, 1777)

In other places, the summit of a mountain was more acute than that of a vault and the layers were parallel between themselves but inclined in a contrary direction, showing in a cross-section the form of a chevron or a lambda [Δ].

§. 339. However the same structure shows often a noticeable singularity. Layers which are perpendicular to the horizon, occupying more or less the center or the heart of the mountain and [H. II. 4] separate the layers of one of the flanks from those of the opposite one..."

"I observed several secondary mountains of the Jura and elsewhere, and in particular a great number of primitive mountains whose structure was the same*." [S. I. §. 339, pp. 275-277]

Hutton has added here the following footnote:

* "This correspondence in the shape of the primitive and secondary mountains of our author, of which the structure is the same, is an important observation for our theory, which makes the origin of those two different things to be similar; it is inconsistent, however, with the notion of primitive parts which some philosophers [including Saussure] have entertained."

> §. 340. Almost all the vertical layers frequently found in the Jura have their plane directed from N-NE to S-SW according to the general direction of that mountain chain. This observation is of great importance because it excludes, or at least makes improbable, the idea of a *bouleversement* [upheaval].
>
> I believed for a long time that all layers were formed in a horizontal position or bent very little and that layers found [H. II. 15] in a vertical position, or very inclined, were caused by some revolution; however, finding more and more layers in such a position, seeing them well preserved in mountains, having not suffered any convulsion, I began to think that nature could well have formed such steeply tilted, or even vertical beds, at the surface of the earth." [S. I. §. 340, p. 277]

Hutton answers: "Here the reasoning of our author is sufficiently just; he sees too much order in the effect to ascribe it to a cause merely fortuitous. But surely nothing in those appearances hinders the conclusion, that the strata now found in all possible positions, had been originally horizontal when at the bottom of the sea, and that they had been afterwards regularly bent and broken, by the same cause which operated in placing them above the level of the ocean. The force of this argument will appear, by considering the various regular and irregular positions in which they are found." He cites Saussure: [H. II. 16]

> "§. 342. [not Hutton's §. 242] In some places of the Jura we find some kind of semi-cirques formed by rocks whose layers represent portions of the surface of the same cone and tend toward a common center high above the horizon." [S. I. §. 342, p. 278]

And again in §. 343:

> "But much more often one sees mountains with layers forming half-a-vault, which, when seen from the side as our Salève mountain, has a moderate slope on one side and escarpements on the other.
> Several valleys in the Jura are located between two mountain-chains which have this form and which present to each other their escarpments. One seems to observe even some correspondence between layers of opposite mountains and it looks as if they were formerly joined and that the middle part was destroyed, or that the mountain split open from top to bottom and that its two halves separated to make room for the enclosed valley." [S. I. §. 343, p. 279]

Hutton cites: [H. II. 7]:

"§. 346. To give a short summary of my ideas on the structure of the Jura, I would say that I believe that it consists of different chains, more or less parallel to each other, as well as to the Alps, but trending a little more toward N to S. The highest chain, closest to the Alps, had originally the shape of a *dos d'âne* from the gable of which the slopes start to cover the flanks and descend to the foot of the mountain. The next chains to the west consist of gradually lower and narrower mountains. The layers of these mountains have, in general, the form of complete or half vaults. The layers of these mountains end up in plains whose base consists of completely horizontal limestone layers of the same nature as those in the Jura mountain which were perhaps in the past connected with them." [S. I. §. 346, p. 281]

After the above description of the Salève and the Jura, the reader may be wondering why Hutton mentioned all these various structures which did not include the Alps. His answer is :

[H. II. 17]: "Our author has here described most accurately, not only the present shape and positions of particular strata, but the general shape and structure of the land from the Salève and [H. II. 18] Jura, which are not in the Alps, to the plains of France, where the strata are generally in a more horizontal situation.

Having thus seen the structure of what are commonly termed the secondary mountains, a structure which prevails generally in all parts of the land, at least in all that which is not primitive in the estimation of naturalists, who suppose a different origin to different parts, it will now be thought a most interesting view of nature, to see the same accurate examination of the structure of the earth, from those secondary mountains of Geneva to the center of the Alps, where we find such a variety of mountains of different materials (whether they shall be called primitive or secondary) and where such opportunity is found for seeing the structure of those mountains."

In short, Hutton is hoping to find the same process in the formation of primitive and secondary mountains to have his theory validated in finding calcareous strata consolidated by subterranean heat.

Travels to the Alps

Hutton immediately cites Saussure's description of the Môle: [H. II. 19]

"§. 287. The steep slopes of the layers forming the Môle, the changing directions of these same layers [H. II. 20] fit also a very important general observation, namely *that secondary mountains are the more irregular and the more inclined the closer they are to the primitive ones.* [Saussure's underlining]

It is true, however, that some limestone mountains, even at great distance from the primitive ones, show here and there inclined layers and even sometimes vertical ones; but these local exceptions do not prevent the fact that, in general, limestone layers found in plains, far away from high mountains, have horizontal or barely inclined layers whereas, on the contrary, the mountains nearing the center of the great chains have only very seldom horizontal layers, but layers that are strongly and diversely inclined almost everywhere." [S. I. §. 287, pp. 229-230]

Hutton answers: [H. II. 20-21]

"That is to say, that there is no place of the earth, however plain and horizontal in general may be the strata, in which examples are not found of this manner of disordering or displacing strata; at the same time they are more erected and more disordered in proportion to the mountainous nature of the country. Here is the proposition contained in that general observation of natural history; and this is a proposition which either naturally flows from the theory, or is perfectly consistent with it." He then refers to the *Vuarne* : [H. II. 21]

§. 360 "The rock which I mentioned before (§. 354) close to the Dôle [in the Jura] named *Vuarne*, has a strange structure. Its layers consist of rocky cliffs [*escarpments*], some of which rise against the NE at an angle of 40-50 degrees; the others against the SE.

§. 361. In front of this rock, on the east side, is another very remarkable structure. It has the form of a pointed chevron or of a lambda (Δ). Because of this form, it was, without any doubt called the *Rocher de fin Château.* Its layers are steeply inclined, rising reciprocally against their respective summits. The [wooden] planks which are erected one against each other to dry, may give an idea of the position of these layers. Such a form is not rare in these limestone rocks but occurs more frequently [H. II. 22] and more obviously in primitive rocks as we shall see later.

§. 362. The *Rocher de fin Château* demonstrates in this shape a very remarkable circumstance because the interval left in between the legs of the Δ is filled with vertical layers. We might say that these layers, pushed upward by a subterranean force, lifted here and there beds which remained leaning against the layers. We have already noticed rocks of this shape in §. 339." [S. I. §. 360 a, 361, 362, pp. 295-296]

Hutton points out: "Here the truth of our theory is so evident, that this philosopher naturally acknowledges it without intention. In his Journey to the Mont-Blanc, he observes, page 364":

"A little beyond Contamine, one passes underneath the ruins of the castle of Faucigny, built on top of a rocky cliff which is part of the base of the Môle. As long as we are directly underneath this rock, it is difficult to see its structure, but

after having passed it, we see with field-glasses that it consists of vertical layers, directed from [H. II. 23] NE to SW. Underneath the latter are other vertical layers but their planes are cutting at a right angle those of the first ones.

At a good half league from this castle, as at the foot of the Salève, is a mass of rocks whose thin and almost vertical layers lean against the escarpments of thick and well continued layers which appear to be horizontal." [S. I. §. 440, pp. 364-365]

[H. II. 23] "But the foot of this mountain is also, as that of the Salève, covered with large and almost vertical layers which are rising against the body of the mountain. And, although the *Brezon* ends a short half league from *Bonneville*, those layers, which are leaning against the foot of the southern chain and which turn thus their back toward the Arve [river], still continue to crop out during a distance of almost two leagues until the village of Siongy. They are actually cut by a small valley at the extremity of the foot of [H. II. 24] the Brezon, but crop out again after that cut." [S. I. §. 445, pp. 369-370]

From Bonneville to Cluses

"§. 446. This small valley opening up at the foot of the Brezon is narrow and winding, the salient angles engaged into the reentrant angles are well visible. This valley leads to the village of Brezon which is behind the mountain of the same name. [Saussure describes the Brezon, which can be seen when leaving *Bonneville*, as being like the Salève flanked by almost vertical layers.]

Above this village are large and beautiful pastures belonging to the chalets, inhabited only in summer, which are called the *Granges de Solaison*. This is where I stayed overnight when I visited the Brezon and the nearby mountains. The *Granges de Solaison* are dominated in the SE by the mountain *Vergy*, a very high limestone chain whose summits I explored also and which are visible from the area around Geneva, to the right of the Môle.

This chain extends from the NE to the SW and finishes behind the mountains which border our road on the right.

§. 447. From the surroundings of Siongy, we observe the structure of the last mountain of this chain; it is very striking. Horizontal layers [H. II. 25] at the top are curved almost at right angles and descend from there vertically on the NE side. They look as if they had been bent by a violent effort; they are seen separated and broken in various places. [S. I. §. 445- 447, pp. 369-371]

§. 449. The Môle ends at the junction of the Giffre with the Arve. Its last layers descend steeply toward the bed of this little river.

The mountains following the Môle and forming after it the northern side of the valley of the Arve are low and unassuming looking. Only one is remarkable by its

conical form and by its layers which converge at its summit and give it the form of a chevron.

§. 450. The city of Cluses itself is built at the foot of a mountain which has an extraordinary structure. It is seen better from a distance than from the city itself.

This mountain with its blunt conical, or rather parabolic shape, is so to speak capped with a bed [*bande*] of rocks which from the top of its head descends right and [H. II. 26] left to its foot. These bare rocks stand out against the green background that covers the rest of the mountain. They consist of several beds parallel to each other; the exterior ones are whitish and thick, the inner ones are brown and thinner. The body of the mountain itself, whose rocks are visible here and there through the forest which covers them, seems to consist of irregular and diversely inclined layers. We might believe that this bed is only the remainder of some kind of cap which in the past might have covered the whole mountain." [S. I. §. 449-450, pp. 371-372]

From Cluses to Sallanches

"§. 463. Soon after leaving the city of Cluses, looking backward to the right, it is possible to see the overhanging rocks under which we passed before crossing the Arve. [§. 448 mentioned by Saussure] From here we notice the position of the layers of these rocks and recognize that they are almost perpendicular to the horizon.

These layers are leaning against other limestone layers, vertical like them but which are the extension of more or less horizontal layers. It looks as if an unknown force had bent at right angles the [H. II. 27] extremity of these layers and forced them to take such a vertical position. [S. I. §. 463, p. 383]

§. 467. If from the road above the foot of the cave we look at that rock with the opening to the cave [*Caverne de Balme* above Cluses], we observe that the layers of this rock are very thick and consist of gray limestone; that above this gray stone is another one of a brown color whose layers are very thin. Nevertheless, by their repetition, they form an impressive thickness.

These rocks in thin layers continue until Sallenches and beyond. They are enclosed above and below by beds of gray compact rocks in thick layers. At times, this gray rock serving as the base, or as the miners say, as floor for the brown rock, plunges and then appears at ground level; elsewhere this gray rock rises and lifts the brown one to a high elevation.

This brown rock is foliated [*feuilletée*] and consists of limestone as the gray one, however a mixture of clay and perhaps some fatty or phlogistic matter produces [H. II. 28] the brown color, rendering the rock easily breakable into angular fragments with plane sides.

This kind of rock has a great tendency to show bent or wavy layers, forming an S or a Z or a C. Close to the cave is a gap in the middle of the layer of the gray rock; thin layers have filled this gap, but they are in that place extremely folded. We understand that this empty space and this replacement occurred at the time when these rocks were formed." [S. I. §. 467, pp. 391-392]

The cascade of the Nant d'Arpenaz

[H. II. 28] ..."The layers of this mountain are a continuation of the upper layers of the rock of the *cascade*, forming concentric arches turned in the opposite direction so that all the layers have the form of an S whose upper part is very much bent backward...

The rock of the cascade, shown in plate IV, is all limestone; the layers above the letters d and e consist of the compact gray rock whose beds, as we mentioned above, [H. II. 29] are normally thick, however the outer layers between e and f are the brown rock with thin layers, mentioned also. These thin layers reappear at the intersection of the vertical ones which pass through letters a and e. (Fig. 1).

Here we have thus the gray rock enclosed between two layers of the brown rock whereas near the cave [§. 467 in Saussure but omitted by Hutton], it was the brown rock that was sandwiched between two gray rocks. However this difference is not too difficult to explain. It is the arched form of these large layers that we should explain....

The greatest of the arcs of circle formed by the outer layers of this rock has therefore as cord a line of about 800 feet. Over that entire length, these layers, as well as the inner ones, can be followed without interruption....

I must mention, however, that in front of the rock of the cascade, at the altitude of the letter a, and below, are layers detached from the circular ones, and independent [H. II. 30] of them. They are tilted planes leaning against the body of the mountain similar to those I observed at the foot of the Salève and of a more recent origin than the body of the mountain itself.

However, behind these planes we observe the arched layers which become horizontal toward the bottom, forming the base of the rock, then rise on the right side to return to form the gable of the same rock." [S. I. §. 472, pp. 396-398]

Hutton adds: "It may be interesting to hear our author's reasoning upon this subject, more especially as it will give more faith or light, if it were possible, to his descriptions, which are irreproachable.": [H. II. 30]

"§. 473. It should be possible at the present time to tell what force could have given this position to these layers, how they were turned up so that the lowest ones became the highest?

The first idea that presents itself is that of subterranean fires. What might even render us inclined to believe that these layers were really lifted by a subterranean

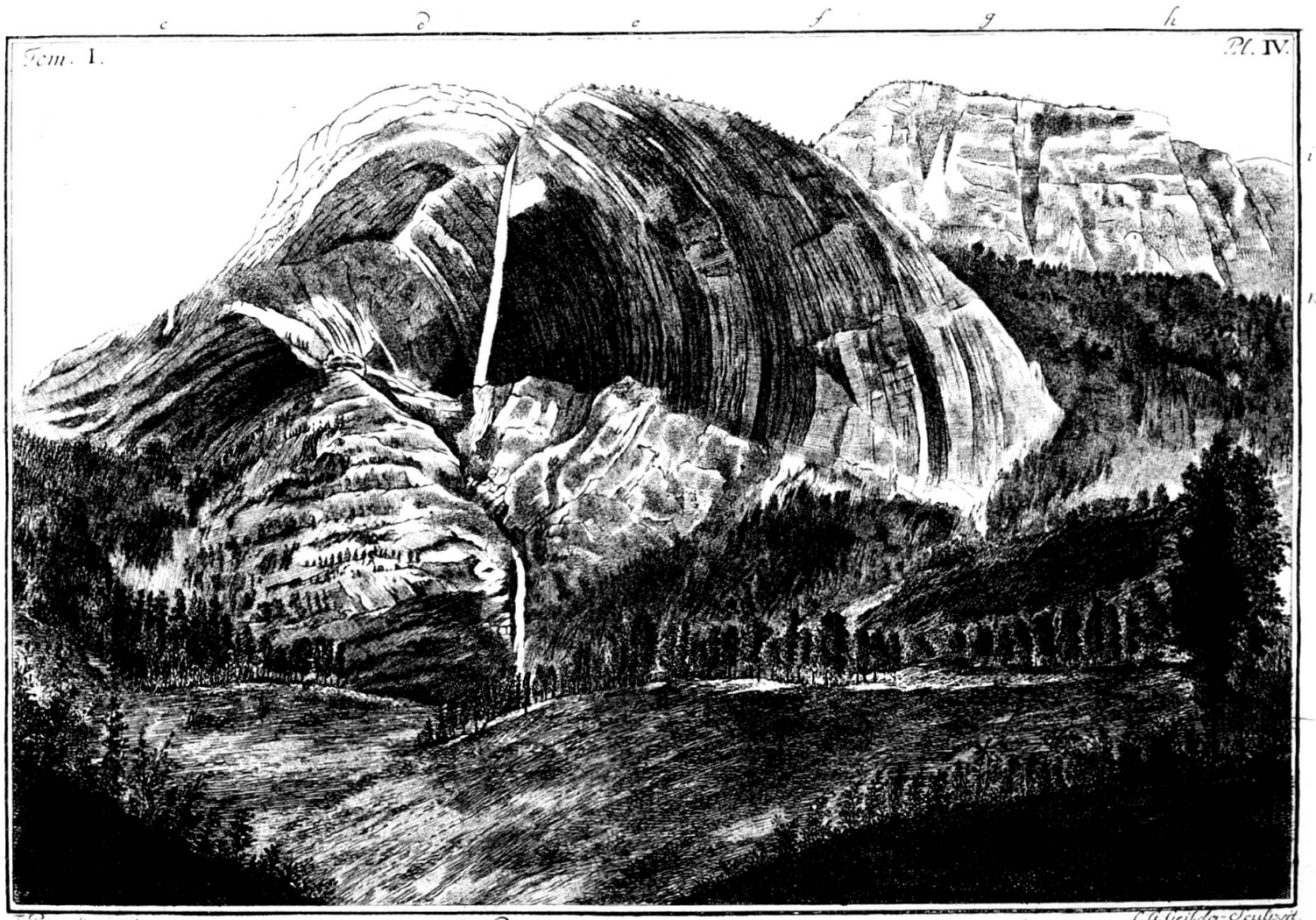

Fig. 1. Vue de la Montagne du Nant d'Arpenaz entre Maglan et Salanche en Faucigny. *Voyages dans les Alpes...*, Vol. I, 1779, Pl. IV, dessin de M. T. Bourrit d'après nature, facing pages 398-399. The letters a to k along the frame designate precise points of Saussure's descriptive text concerning the large S-shaped fold of the Nant d'Arpenaz.

force is a gap on the right side of the rock formed by these layers where the part, [H. II. 31] which is roughly necessary to form the height of the cascade, is missing. Indeed, the mountain underneath the letters g and h is on a line much more distant. On the right of this gap, the layers start again on the line of those layers which are bent. They are seen cut perpendicularly on the side of these layers, with the same colors, the same thickness, but in a horizontal position.

In more than one mountain I have I observed such bent layers close to which is a gap which they seem to have left when folding upon themselves.

In the *Ober-Hasli*, the valley of *Meiringen* shows a good example above the village of *Stein*.

In the canton of Uri, on the shore of the lake of *Lucerne*, there are also several clear examples.

A mountain closer to the cascade [of the mountain of *Nant d'Arpenaz*] presents the same phenomenon. It is located behind the cascade to the north-east between the village of *Seiz* and the *Granges des Fonds*. This mountain is called *Anterne*. It is higher than that of *Nant d'Arpenaz*, its layers form concentric arches [H. II. 32] which are greater and even more bent, and at their side is also a gap that the mountain seems to have left behind when uplifted and refolded on the left.

Nevertheless, in spite of these observations, it is not without pains that I resort to these almost supernatural agents, particularly because I see none of their vestiges. Indeed, this mountain and those around it show no trace of fire. Therefore, I leave this question open, I shall return to it more than once, even before the end of this chapter.

We must now look at the mountains on the other side of the Arve.

§. 474. Opposite the cascade, on the other side of the river, is a chain consisting of very high mountains which show their escarpments above Sallanches and against the Mont-Blanc. Their layers thus descend toward the valley of the *Reposoir*, located at their foot to the north-west.

However, at the foot of the escarpments of the same chain, is a range of lower mountains parallel to its direction, tilted and [H. II. 33] leaning against its escarpments which descend in a gentle slope toward Sallanches, again as at the Salève.

§. 475. From the cascade to St. Martin, one sees often on the left strangely contorted layers, always in the same kind of brown limestone that we have followed for a long time. Some of these layers form almost a complete circle, the most remarkable ones are half a league from the cascade. They represent arches whose convexities face each other more or less like an X, but with the planes located obliquely between the two convexities, with plane and horizontal layers immediately above the arch on the left.

These various layers are so continuous in all their shapes and so strangely intertwined that I have a hard time believing that they were formed in a horizontal position and that some upheavals gave them these bizarre shapes.

To start with, it would be necessary to conjecture that these upheavals [H. II. 34] happened at a time when the layers were still soft and perfectly flexible because nothing broken is noticeable, their curves, even the most angular ones, are absolutely whole.

Thereafter, it would be necessary that the layers, in this state of softness, were crumpled and contorted in the most bizarre fashion and almost impossible to explain in detail. Moreover, subterranean explosions break and tear, but do not uplift with enough care which is necessary for the preservation and the continuity of all these parts.

In my opinion, only crystallization explains these bizarre things; we see, as mentioned earlier, alabasters formed, so to speak, in front of our eyes by true crystallization in crevasses and in the caves of mountains, presenting layers in which we observe effects just as unusual." [S. I. §. 473-475, pp. 398-401]*

[H. II. 351] "I would therefore not object to believe that the rock of the cascade was formed in the place where it exists today; if the gap on its right and the layers which, although continuous, show nevertheless [H. II. 36] a few ruptures in some strong flexures, and these large beds of that gray compact rock, which is not as much subject to these bizarre forms, did not establish a noticeable difference between them and those we just examined." [S. I. §. 473, 474, 475, pp. 399-401]

Hutton's footnote [see * above] show's his dismay :

"M. de Saussure would explain the various shape and contortions of strata upon the principles of crystallization; but surely he has not adverted to the distinction of crystallization as an operation giving form or shape, and as [H. II. 35] giving only solidity or hardness, which last, it is apprehended, is the only sense in which our author here considers crystallization, although, from the way in which he has employed this principle, it would seem that it is the figure which is to be explained by it. This conjecture is supported by the example of alabaster or *stalactites* with which he compares the section of those mountains, for, in the example of implicated figures of the stalactite marble, similar to those of the present distorted strata, crystallization has nothing to do with that part of the figure which corresponds to the case now under consideration; it forms indeed certain figures of crystals in the mass by which also the configuration of some minute parts, affected by those crystals, is determined; but the figure of those alabasters, which is to be compared with the present subject, arises solely from the current of petrifying water along the surface of the mass. This mass, therefore, being formed by succession from that water, crystallising calcareous earth, and carrying colouring parts of other earth, gives an appearance of stratification to a figure which is absolutely inconsistent with stratification; an operation which is performed by depositing materials at the bottom of the sea, and which the marine bodies contained in some of the strata sufficiently attest."

Here, Hutton understood the error committed by Saussure, that is to accept the old comparison between the microcosm and the macrocosm where small objects such as alabaster were compared with large strangely deformed strata in mountains.

Nevertheless, Hutton said :

"It is impossible to be more impartial than M. de Saussure has proved himself to be on this occasion, or to reason more in the manner in which every philosopher ought to reason on all occasions.

But to see the full value of this author's impartiality, notwithstanding of his system, let us follow him in the second volume of *Voyages dans les Alpes*. It is in chap. xx. entitled, Poudingues de Vallorcine, that we find the following description, with his reasoning upon that appearance."

Mountains of granite, schist, and limestone:

The pudddingstones of Vallorcine

[H. II. 36]

"§. 688. There we observe (page 99) that the base of this mountain [*Montagne de la Balme*] is a true gray granite with average grains whose structure shows no particularity; however above these granites are quartzose foliated [*feuilletée*] rocks mixed with mica and feldspar, a type halfway between veined granite and the regular foliated rock. Their layers trend [H. II. 37] N-S as does the valley of Vallorcine at an angle of 60 degrees, rising westward against the same valley. These rocks continue in the same position until, after a half-hour walk, we lose sight of them under the vegetation which covers a small plain in the middle of the forest called *le plan des Céblancs*.

§. 689. From there, climbing laterally toward the south, we find large blocks of schist, either gray or purplish red, sometimes even of a pronounced violet color. This schist includes a large quantity of foreign pebbles, some angular, others rounded, of different size, from that of a grain of sand to that of a head. I was curious to see these puddingstones [conglomerates] in their native place and climbed straight ahead to get there, but to my great astonishment I found their layers in vertical position!

§. 690. It is easy to understand this astonishment if we consider it impossible that these pudddingstones were formed in this position.

[H. II. 38] The fact that extremely small particles, suspended in a liquid, may agglutinate among themselves and form vertical layers is proven in alabasters, agates, and even in artificial crystallizations. But that a previously shaped stone, the size of a head, would come to rest in the middle of a vertical cliff and wait there until the smaller particles of the rock surround it, glue it, and hold it in that place, is an absurd and impossible supposition. We should therefore consider it as

demonstrated that these puddingstones were formed in a horizontal position, or roughly so, and later straightened up after their induration. What force straightened them up? We still do not know. However our demonstration represents already a first step, and an important one, namely, to have found, in the middle of the huge quantity of vertical layers that we encounter in our Alps, some which we are entirely sure that they were formed in a horizontal position. [H. II. 39]

§. 691. The nature of the material itself which surrounds the pebbles of these puddingstone renders the fact more noteworthy and convincing. If it were a shapeless and coarse paste, then we could believe that these coarse pebbles and the paste which binds them were dumped pell-mell into some vertical crevices where the liquid part hardened by desiccation. However, such is not the case by far because the material of this paste is admirably smooth; it is a schist whose individual laminae are extremely thin, mixed with mica, and perfectly parallel to the bedding planes which separate the beds of the rocks. The layers themselves are very regular, well continuous and of different thicknesses, from half an inch to several feet. The thin ones include little or sometimes no foreign pebbles, and we observe some alternation between thin layers without pebbles and thick layers with pebbles. The main color of this schist varies a lot; here it is gray, there greenish, most often violet or reddish; some are mottled with these different colors. Its layers [H. II. 40] extent from N to S, exactly like those of the granitic rocks which are below, §. 688; however the tilting of the schist is much greater, its layers are often perfectly vertical, and when they are not, they rise a few degrees on the same side as the granitic rocks I just mentioned, that is, westward.

§. 692. Pebbles enclosed in this schist are, as already mentioned, of different size, from that of a grain of sand up to 6 or 7 inches in diameter. All belong to the kind of rocks which I call primitive; however, I have not seen any massive granite, only foliated granite; foliated rocks mixed with quartz and mica; even fragments of pure quartz, but absolutely no pure argillaceous schist, nor any limestone; nothing that produces any effervescence with concentrated *aqua fortis*; and the paste itself, enclosing these pebbles, does not react either. Their form varies; some are abraded and have obviously lost their angles by friction; others have sharp angles, [H. II. 41] still others are even of rhomboidal shape as shown so often by rocks of this kind. In those parts of the rocks where these pebbles are concentrated in very great number, the constituents of the schist have not had the freedom to take the shape of parallel laminae; but where the pebbles have between themselves noticeable intervals, laminae reappear and are regularly parallel, both between each other and the bedding planes.

§. 693. The beds of these schistose puddingstones reach in the mountain a thickness of about a hundred toises, counted from east to west across the layers; I followed them along their length more than one league; it is impossible to follow them farther because the beds disappear underneath the ground." [S. II. §. 689-693, pp. 99-102]

Hutton adds: [H. II. 41] "Here M. de Saussure, who is always more anxious to establish truth, than preserve theory, gives up the formation of the alpine strata by crystallization. Let us now see how he acknowledges the evidence of softness in those [H. II. 42] strata in his description of the Val de Mont Joye, Tom. 2d. page 173."

[*Val de Mont-Joie* is a valley where Saussure mentioned a number of blocks which had rolled down from the mountains in the east and were noteworthy by the arrangement of their layers.]

> "§. 755... These are hard rocks with a confusedly crystallized background of quartz or white feldspar with black veins of mica or schorl in small blades. The veins penetrating the rock entirely are sections of layers of which the rock consists. Here they are plane and parallel between each other; there in zigzags and enclosed between perfectly parallel planes, an accident whose texture can be simulated by clothes, both striated and chiné. Are these tortuous forms [*anfractuosités*] of layers the effect of crystallization or of a movement of pressure which folded back [*refoulé*] the plane layers while they were still flexible whereas other plane layers were formed on top of them?" [S. II. §. 755, p.173]

Hutton intervenes: "M. de Saussure has no idea of strata formed at the bottom of the sea, being afterwards softened by means of heat and fusion. He has already given up the supposition of those vertical or highly inclined strata having been formed in their present position; but had this geologist seen that it was the same cause by [H. II. 43] which those strata had both been raised in their place and softened in their substance, I am persuaded he would have freely acknowledged, in this zigzag shape, which is so common in the alpine strata, the fullest evidence of the softening and the elevating power."

"At the *Tour des Fols* near St. Bernard, M. de Saussure found an appearance the most distinct of its kind, and worthy to be recorded as a leading fact in matters of geology..."

> [S. II. §. 997, pp. 454-455] "The general direction of the layers of these rocks and the slates which separate them is from south to north, or more precisely, from S-SW to N-NE. However, this direction is cut at a right angle by layers of slates and quartzose sheets which extend from east to west through the middle of the layers which run from south to north."

Hutton interferes: "Clearly as this fact must demonstrate, to a reasoning person, the fracture and dislocation of strata, our author, who knows so well the reasoning of naturalists on such an occasion, gives us his opinion as follows:"

> "... As to the reason for this fact, we may attribute it to [H. II. 44] upheavals [*bouleversement*] which seem to me the most plausible explanation. However, we might suppose that in the middle of these layers existed a large fissure which was

filled by transverse layers. But the filling should have occurred at the same time as the origin of this mountain because the slates and the quartzose pyramids--whose direction is transversal--are exactly of the same nature as the others; furthermore, it would be necessary to assume that they were formed in the very tilted position in which they are at the present time; a supposition which is difficult to accept."

Without referring to the above proposition, Hutton jumps to Saussure's general view on the mountains which border the valley of the Rhône:

"§. 1095. This continuation of the *limestone mountains* [my underlining] that we skirted from St. Maurice to Chillon shows almost nowhere any regular horizontal layers; they are in almost all places inclined, bent, and seem to have suffered from some violent causes; because [H. II. 45] simple collapses are, in my opinion, not sufficient to explain the reason of all their shapes. Their escarpments too are rather irregularly located; the greatest part of them faces however the valley of the Rhône.

The continuation of mountains corresponding to that on the left side of the Rhône and the lake is also of limestone and roughly just as irregular. Most of these mountains, especially those which are closest to the lake, have steep slopes, both toward the lake and the Rhône. The valleys which separate these mountains seem to divide them into chains parallel to the lake, extending NE to SW. Those closest to the lake are steeply sloped toward it, as mentioned earlier, whereas those farthest away from the lake, or closest to the center of the Alps, are inclined against these same Alps. The *Val de Lie* separates these two orders of mountains; this rich and fertile valley has the shape of a crib; the two chains, running along its borders, rise in a gentle slope toward the valley while turning their escarpments one against the lake and the other against the Alps. By the way, I have not [H. II. 46] explored these mountains, I could only assess them from afar.

But what we can be certain of is that, although the mountains on both sides of the Rhône valley resemble each other by their nature, which is limestone on both sides, they do not resemble each other in their structure. There is no correlation in their positions, nor in their shapes. The valleys which separates them do not correspond either. This lack of correspondence seems to awaken again the idea of upheavals." [S. II. §. 1095, pp. 543-545]

Hutton concludes: "The general result, from these observations of our author, is this. First, there is no distinction to be made of what is termed primary and secondary mountains, with regard to the position of their strata; every different species of stratum, from the stratified granite and quartzy *schistus* of the Alps to the *oolites* of the Jura and Salève, being found in every respect the same; whether this shall suppose as arising from their original formation, or according to the present theory, from subsequent deplacement of strata formed originally in a horizontal situation."

[H. II. 47] Secondly, it appears that, in all those alpine regions, the vertical position of strata prevails; and that this appearance, which seems to be as general in the alpine

regions of the globe as it is here in the mountainous regions of the Alps, has been brought about both by the fracture and flexure of those masses, which, if properly strata, must have been originally extended in planes nearly horizontal...

Thirdly, in all those accurate observations of a naturalist, so well qualified for this purpose, there appears nothing but what is perfectly consistent with such a cause as had operated by slow degrees, and softened the bodies of rocks at the same time that it bent them into shapes and positions inconsistent with their original formation, and often [H. II. 48] almost diametrically opposite to it; although there appeared to our author an unsurmountable difficulty in ascribing those changes to the operation of subterranean fire, according to the idea hitherto conceived of that agent.

This grand mineral view of so large a tract of country is the more interesting, in that there has not occurred the least appearance of volcanic matter, no basaltic rock, in all that space where, so great manifestation is made of those internal operations of the globe by which strata had been consolidated in their substance, and erected into positions the most distant from that in which they had been formed."

Identity between primary and secondary rocks and of their properties

In Chapter II, Hutton returns to the same subject of alternation of strata, referring to Saussure's descriptions of his passage of the *Col du Bonhomme*: [H. II. 51-52]

> "Between the col, mentioned above, and the cross which is customarily placed at the highest point of the pass, there are three-quarters of a league, or a short hour of road, where we encountered sandstones, limestone breccias, simple gray or bluish limestones and slates. These alternations are repeated several times. Among the sandstones are some which include rounded pebbles, others include none and are not effervescent.
>
> Some of these sandstones appeared remarkable by their resemblance to foliated rocks. They are compact, mixed with mica, and a quartzose juice fills all the interstices between their grains, giving them [H. II. 53] an unusual hardness and solidity. Anybody who has seen unquestionable pieces of this rock believed it to be a foliated rock; however when it is found in its place of origin and if gradations connect it to sandstones, for instance those which include rounded pebbles, it is no longer possible to have any doubts about its nature. These layers are generally inclined at an angle of 30 degrees, descending toward the south-east." [S. II. §. 763, pp. 179-180]

Hutton emphasizes [H. II. 53-55] Saussure's distinction between foliated rocks and sandstone [*grès*], the first one believed to be primitive but with an unknown origin and the second "as having been formed of sand deposited at the bottom of moving water, and afterwards becoming stone."

Hutton cites: [H. II. 54]

"I saw in the Vosges very beautiful sandstones of the same kind [as at the pass of the *Bonhomme*]; however, they resembled not so much primitive rocks because they did not include mica. However, the most noteworthy fact here, which is not found in the Vosges, is to find such kinds of sandstones enclosed between lime-stone beds. But, the farthest away these sandstones are from the primitive rock, which forms the base of the mountains, the less they are solid and quartzose until finally the highest ones are effervescent with concentrated *aqua fortis*."

Hutton comments: "Here again the alpine lime-stone which according to the present naturalists, should be primitive, are plainly homologated in their origin with strata formed of sand."

Our author proceeds:

..."§. 765. The top of the pass of the Bonhomme, at the foot of the cross, consists of thin slates, mixed with laminae of quartz. Descending toward Chapiu, we find these same slates alternating with layers of thin [H. II. 55] and foliated sandstone, mixed with mica, followed by simple limestones, then limestone breccias which enclose fragments of limestones with sharp angles. All these layers descend toward the SE following the slope of the mountain, but a little faster.

Since this mountain is completely exempt of trees, the progress of rivers is visible instantly. Furrows, hardly seen at the beginning, become gradually larger and deeper downward where they finally form deep ravines that we could almost call valleys. These furrows, branched out over the entire slope of the mountain, are still filled with snow while in between areas are grasslands which built on this green background a white embroidery whose effect is extremely unusual. When I passed there on July 13, 1774, all these depressions with snow were covered by red dust which I described in §. 646.

Toward the bottom of the slope, I was astonished to find chalets built with building stones of very regular shapes. I asked about the reason for this search [H. II. 56] which is very rare in the mountains and I learned that nature had paid for all the expenses of cutting the stones. Indeed, I found a little further down a deep gully made by the waters in the layers of a beautiful sandstone that divides by itself and is seen in its original position. In fact, it is separated into large rectangular parallelepipeds. Was this retreat produced by drying or is it rather a successive collapse of layers which divided them in this manner. I am not going to make any decision in this particular case."... [S. II. §. 765, pp. 181-182]

Hutton says: "The only thing which, in this particular case makes our author express his wonder, is the extreme regularity of these natural divisions of stone; for, the same appearances are to be found in every case of consolidated strata, though not always with such extreme regularity. But this is one of the most irrefragable [not to be

contested] arguments for those various bodies having been consolidated by means of heat and fusion. The contraction of the mass, consolidated by fusion or the effect of fire, is the cause of those natural divisions in the strata; and the regularity, which is always to be observed more or less, depends upon the proper circumstances of the case, and the uniform nature of the mass." [H. II. 56-57]

Hutton cites Saussure:

> "In the morning, before leaving Chapiu, I went to check if the beautiful rectangular sandstones, that I had seen the day before, descended downward to the foot of the mountain. I found indeed sandstones, but with thin layers, which did not separate regularly. On the contrary, I saw layers of those sandstones bent and rebent in zigzags as those I had encountered at the Contamines, §. 755, and these wavy layers were also enclosed between plane and parallel layers. This phenomenon is much more scarce in sandstones than in foliated rocks properly speaking." [S. II. §. 766, p. 184]

Hutton concludes: "Thus every appearance is found by which the primitive *schisti* are perfectly resembled, both as to their original formation and their accidents, with the strata [sandstones], which are acknowledged by naturalists as being the common operation of the sea." [H. II. 57]

Saussure on rounded pebbles and Hutton's reaction

Searching for more descriptions of sandstones, Hutton cites Saussure's account of the *Passage des Fours*: [H. I. 58]

> "§. 776. Close to the top of the pass, we find beautiful layers of yellowish sandstones cropping out from underneath limestone, which [the sandstones] nevertheless show no effect of effervescence with acids.
>
> §. 777. It took two hours and three-quarters to climb from the hamlet of the Glacier to the top of the col from where I descended to the cross of the Bonhomme with *Pierre Balme* to my right. I had my mules waiting for me at this cross and went with *Pierre Balme* to reach the summit of the mountain whose rounded peak seemed to dominate all the surrounding mountains. I named that peak--which had no name-- *Cime des Fours* because of the passage which it dominates. Large slabs of snow covered in various places the road I took to go there. Nevertheless, the rock was exposed enough to recognize its nature.
>
> §. 778. I first crossed layers of sandstone which were the continuation of those [H. II. 59] I described above, §. 776. Thereafter I found layers of a kind of coarse puddingstone whose matrix was that same sandstone filled with rounded pebbles. Some of these layers were altered and the waters had carried away the parts of sand which had joined the pebbles so that the pebbles became loose and were piled up

exactly as at the shores of a lake or a river. It was so strange to walk at this altitude on rounded pebbles that Pierre Balme showed his astonishment before I could even talk about them. We might have been tempted to believe that a waterfall--destroyed since through time-- had been falling in the past from some higher rocks and had rounded these pebbles if one had not found similar ones still enclosed in regular layers of sandstone forming the top of this mountain.

§. 779. Although for a long time I no longer doubt that the waters once covered and even formed these mountains, and that proofs exist which are even more powerful than the existence of these rounded pebbles, nevertheless their accumulation on this peak appeared [H. II. 60] as something so extraordinary which addressed the senses in a language so persuasive that I could not shake off my astonishment. While walking on these pebbles, and observing them, I forgot for a moment where I was; I had the impression to be on the shores of our lake; but as soon as my eyes wandered from right to left, I saw below me immense depths, and this contrast had something of a dream. With extreme vividness, I imagined then the waters filling all these depths and coming to pound and round these pebbles at my feet, pebbles on which I walked while the high peaks formed only islands above this immense sea. I asked myself how and when these waters had retreated. However, I had to detach myself from these great speculations to use my time with more advantage for the exact observation of these strange phenomena." [S. II. §. 776-779, pp. 189-191]

Apparently little impressed by Saussure's dream, Hutton said: "The fact here worthy of observation is the effect of time in decomposing this *grès* or sandstone which contains the gravel. All other appearances follow naturally from [H. II. 61] the situation of this place, which is a summit and does not allow of such a collection of water as might travel or transport the loose gravel, although it has been sufficient for carrying away the sand. This decomposition of the sandstone we shall find also explained from what follows of the description of this place":

"§. 780. All the beds of sandstone encountered on this mountain do not enclose rounded pebbles; there are irregular alternations of beds of pure sandstone and beds of sandstone mixed with pebbles. The highest alternations do not contain any pebbles. The highest bed with pebbles is one which is continuous and rises at 30 degrees toward the N-NE.

Some of these beds, filled with pebbles, show a striking particularity. On their external surface, exposed to the air, is some kind of network formed by solid black veins jutting out two or three inches above the surface of the stone. The cells [*mailles*] of this network are sometimes irregular, but they are mostly oblique-angle quadrilaterals [H. II. 62] whose sides measure eight to ten inches. Since all these stones have a tendency to divide into rhomboids, it seems that in the past some fissures divided the beds into parts of this shape, and that these fissures were filled with sand which was glued together by a ferruginous paste; this solid glue

made these parts harder than the rest of the stone, and when erosion of the air wore away the surface of these beds, the cells of the network remained salient.

The rounded pebbles which were exposed to the air for a long time, took also an outer blackish and ferruginous color, but pebbles which are still enclosed in beds of sandstone have, as the sandstone, a yellowish color. None of the pebbles I found there were of primitive nature, most of them consisted of gray or very hard red feldspar, confusedly crystallized. These stones have therefore not a naturally rounded form and consequently received it merely from the rolling movement and the friction of waters. [H. II. 63]

All these sandstones effervesce with *aqua fortis*, however parts of the ferruginous network react much less than the matrix of sandstones themselves. Also, if sandstones which enclose pebbles, are compared with those which do not, we find in the first kind more limestone cement [*gluten*] because *aqua fortis* decreases their coherence much more.

On the very peak of the mountain, these sandstones are covered by a gray and shiny slate which exfoliates in the air. If one climbs down from that same peak by the north-east, on the opposite side of the passage des Fours, one finds again beds of a perfectly similar sandstone which divides spontaneously into small parallelepipedic fragments." [S. II. §. 780, pp. 191-192]

Vertical uplifts of the center of the Alps and Saussure's dream at the summit of Cramont (1774)

"§. 781. From the top of this peak, at an altitude of 1396 toises above the sea, one enjoys a very panoramic view. In the north and north-east : the valleys of Mont Joie, Passy, Sallanches ; in the west: the high calcareous peak I mentioned, §. 759; in the south : the mountains extending from the Chapiu to the *Col de la Seigne*; in the east : the same pass which we dominate very much. To the right of this pass [H. II. 63], one sees, on the Italian side, the chain of the Cramont and several other chains parallel to that one, all turning their escarpments toward the central chain, just as one sees, on the side of Savoy, the chains of the Reposoir, Passy, Servoz turn their escarpments in the opposite direction, toward that same chain. This is so because we have here one of these very extended views on the two opposite sides of the Alps. Indeed, from here we see the mountains of Courmayeur and the Allée-Blanche on the southern side of the chain, and those of the Faucigny and the Tarentaise on the northern side. However the sites from where it is possible to enjoy at the same time these two views are very rare because the high peaks of the central chain are almost all inaccessible, and the cols, where they can be crossed, are mostly tortuous and narrow, providing most of the time only very restricted views." [S. II. §. 781, pp.192-193]

Hutton's reaction is very long and of great interest; therefore I give it in his own words:

"We have here two facts extremely important with regard to the present theory. The one of these respects the original formation of those alpine strata; the other the elevation of those strata from the bottom of the sea, and [H. II. 65] particularly the erection of those bodies, which had been formed horizontal, to their present state, which is that of being extremely inclined. It is to this last, that I would now particularly call the attention of my readers.

It is rarely that such an observation as this is to be met with. Perhaps it is rarely that this great fact occurs in nature, that is, so as to be a thing perceptible; it is still more rare that a person capable of making the observation has had the opportunity of perceiving it; and it is fortunate for the present theory, that our author, without prejudice or the bias of system, had been led, in the accuracy of a general examination, to make an observation which, I believe, will hardly correspond with any other theory but the present.

If strata are to be erected from the horizontal towards the vertical position, subterraneous power must be placed under those strata; and this operation must affect those consolidated bodies with a certain degree of regularity, which, however from many interfering circumstances, may be seldom the object of our observation. If indeed we are to confine this [H. II. 66] subterraneous operation to a little spot, the effect may be distinctly perceived in one view; such are those strata elevated like the roof of a house, which M. de Saussure has also described. But when the operation of this cause is to be extended to a great country, as that of the Alps, it is not easy to comprehend, as it were, in one view, the various corresponding effects of the same cause through a space of country so extensive, and where so many different and confounding observations must be made. In this case, we must generalize the particular observations, with regard to the inclinations of strata and their direction, in order to find a similar effect prevailing among bodies thus changed according to a certain rule; this rule then directs our understanding of the cause. The general direction of those alpine strata, in this place, is to run SE and NW that is to say, this is the horizontal line of those inclined beds. We also find that there is a middle line [a central dividing line such as a gable] of inclination for those erected strata in this alpine region; as if this line had been the focus or centre of action and elevation, the strata on each side being elevated towards this line, and declined from it by descending in the opposite direction.

The view which our author has now given us from this mountain is a beautiful illustration of this theory; for, the breaking of the tops of mountains, composed of erected strata, must be on that side to which their strata rise; and this rupture being here towards the central line of greatest elevation, the ridges must in their breaking generally respect the central ridge. But this is the very view which our enlightened observator has taken of the subject; and it is confirmed in still extending our observations westward through the kingdom of France, where we find the ridges of the Jura, and then those of

Burgundy gradually diminishing in their height as they recede from the centre of elevation, but still preserving a certain degree of regularity in the course of their direction.

But our author has still further observed that this is a general rule with regard to mountains. I will give it in his own words. Tom. 2. (p. 338)." [H. II. 68]

> "§. 918. But the central chain is not the only primitive one on this side of the Alps. From the summit of the Cramont, looking towards Italy, we notice an accumulation of mountains which spread as far as our eyes can see. Among these mountains, one stands out in the south-west as being extremely high: its name is *Ruitor*. This mountain presents itself to the Cramont in about the same way as does the Mont-Blanc from Geneva; its summit is snow-covered, a large glacier descends from its central area, and a torrent flows out from the glacier to join the river of *La Tuile*. This high primitive mountain is in the middle of a chain of mountains of lesser elevation, but also primitive, extending above the *Val de Cogne*. From the summit of the Cramont we observe secondary mountains between the Cramont and this primitive chain and we recognize that the layers of these mountains rise against this chain, turning their back to the central chain.
>
> §. 919. The leaning of the Cramont and of the primitive chain against the Mont-Blanc is thus [H. II. 69] not a phenomenon typical of this mountain alone, it is common to all primitive mountains and represents a general law, namely, that secondary mountains near primitive ones have layers on both sides rising toward the primitive mountains. I made this observation for the first time from the Cramont and verified it later on in a great number of other mountains, not only in the Alpine chains, but also in various other chains as shall be demonstrated in volume IV. The many proofs I had witnessed and other similar ones which I recalled, induced me to suspect the universal character of my observation, and I related it immediately to observations I had just made on the structure of the Mont-Blanc and of the primitive chain of which it is part. I saw this chain consisting of sheets that could be considered layers. In the center of this [primitive] chain the position of the layers was vertical, in the secondary layers almost vertical at their point of contact, then becoming [H. II. 70] less vertical, the farther they are from the central chain, approaching more and more a horizontal position. I recognized thus that the differences between primitive and secondary mountains, which I had already noticed in the composition of their material, include also the shape and the position of their layers. Indeed, the secondary summits, seen from the Cramont, terminated in pointed and sharp pyramidal needles just as the Mont-Blanc and the primitive mountains of the chain. I concluded from all these relationships that given the fact that the secondary mountains were formed in the waters, it was necessary that the primitives ones had the same origin. Mentally tracing back the great revolutions that had occurred on the surface of our globe in the past, I saw the sea cover the entire surface of the globe, forming by deposition and successive

crystallizations, first the primitive mountains and then the secondary ones; I saw these materials arranged horizontally in concentric layers, then fire or other elastic fluids, enclosed in [H. II. 71] the center of the globe, lift and break this crust, expelling the interior and primitive part of the crust while its exterior or secondary parts remained leaning against the interior layers. I then saw the waters rush into the abysses, broken and emptied by the explosion of the elastic fluids; and these waters, rushing toward these abysses over great distances, carry the huge boulders which we find scattered around in our plains. Finally, after the retreat of the waters, I saw the seeds of plants and animals, made fertile by the newly generated air, start to develop both on the land abandoned by the waters and in the waters themselves which had been trapped in the cavities of the surface.

These were the thoughts inspired by the new observations made in 1774. We shall see in volume IV how twelve or thirteen years of continuous observation and reflection upon the same subject shall modify this first draft of my conjectures. I am talking here historically only and to show what are the first ideas that the great spectacle of the Cramont may naturally produce in a mind which has as yet not accepted any system." [S. II. §. 918, 919, pp. 338-340]

Hutton wonders: "How far these appearances, which had suggested to this philosopher those ideas, agree with or confirm the present theory, which had been founded upon other observations, is here submitted to the learned." [H. II. 72]

[I believe it important to underline that Hutton, who had rejected most of Saussure's neptunistic ideas, seems to agree here with the idea of vertical uplifts as proposed in Saussure's theory on the formation of the Alps, according to his view from the Cramont. Indeed, Hutton discusses at length and with great interest "the center of action and elevation," seen from that mountain [H. II. 66]; he even accepts part of Saussure's dream on the Cramont, namely that "elastic fluids, enclosed in the center of the globe, lift and break the crust..." [H. II. 71]. It is ironic that Saussure later abandoned these ideas on vertical uplifts to replaced them with his theory of antagonistic horizontal thrusts. (Carozzi, A. V. 1998)]

Denudation of the surface of the Earth and Saussure's "Grande Débâcle"

Hutton returns to Saussure with regard to riverbeds, saying [H. II. 100]: " These take winding courses around the hills which they cannot surmount; sometimes again they break through the barrier of rocks opposed to their current; thus making gaps in places by wearing away the solid rock over which they formerly had run upon a higher level and thus leaving traces of their currents in the furrowed sides of rocky mountains, far from the course of any water at the present time.

So strongly has M. de Saussure been impressed with this and some other appearances, that he has imagined a current of water which, however in the possibility of

things, is not in nature, and which moreover could not have produced the appearances now mentioned [H. II. 101] which is the work of time, and the continued operation of a lesser cause. We are further obliged to him for the following facts. Vol. I. (page 163)"

> "The bare and steep sections of the thick layers in the Petit and particularly the Grand Salève show almost everywhere the most striking traces of the flowing of water which eroded and excavated them. On these rocks are furrows, more or less horizontal, more or less wide and deep; some are 4 to 5 feet wide, with double or triple length, and 1 to 2 feet deep. All these furrows have rounded edges such as the waters usually make. I said that they were more or less horizontal because, sometimes, they are slightly inclined, descending toward the S-SW, following the slope excavated by the river." [S. I. §. 221, pp. 163-164]

Interrupting the citation, Hutton says:

[H. II. 101] "This is evidently the effect of a river running along the side of a rock of such soft materials as may be worn by the friction of sand and stones; and such are the materials of the rocks now considered. Notwithstanding that it is so easy to explain this appearance by the operation of natural [H. II. 102] causes, M. de Saussure proceeds in taking it in another view."

> "Such furrows could not have been made by rain waters because those form excavations, either perpendicular or following the greatest slope of the faces of rocks, whereas the ones here trend almost horizontally on completely vertical rock faces." [S. I. §. 221, p.164]

Hutton has omitted here Saussure's critical last sentence:

> "These furrows are exactly what I was looking for, that is the traces or the margins of the current which transported in our valleys rocks from the Alps."
>
> [Hutton did obviously not agree with Saussure's interpretation of running currents during his "débâcle". On the contrary, he assumed the erosional action of a river, flowing along the side of a limestone cliff, as an example of the operation of natural causes. With regard to modern terms, both authors are mistaken. The limestone beds of the Salève show longitudinal furrows and reentrants, called locally "barmes," predominantly produced by differential weathering processes. These were very active when the Salève was undergoing glacial and interglacial conditions during the Pleistocene Ice Age and are still operating today.]

Hutton continues:

"Here our author takes it for granted that things upon the surface of this earth were always the same as at present; and he reasons justly from these principles. But we are now tracing a former state of things; and those furrowed rocks testify the former current of a river by their side.

This operation of rivers undermining the sides of mountains, and causing scenes of ruin and destruction, may be illustrated by what our author has described under the title: *Ravages du temps sur les rochers de Salève.* [Devastations by weathering of the rocks on the Salève]." [S. I. §. 236, pp. 182-183]

" §. 236. In those places where these layers are missing, [that is vertical layers] it is easy to see that they were destroyed by weathering; even the horizontal layers, against which they are leaning, have suffered [H. II. 103] great changes in various places.

A painter who would like to heighten his imagination and conceive great ideas on the destructions by weathering of large objects should go to the foot of the Salève, at the extremity of these great rocks, above the *Coin* [corner], a highly situated hamlet of the parish of Collonges.

One sees vertically-cut rocks, several hundred feet high, with faces, here plane and uniform, there separated and cut into furrows by the waters.

The base of these rocks is covered by debris and huge fragments, piled up in disorder. One of these debris, fortuitously supported by others, has remained and seems very similar to a quadrangular obelisk of great height. From far away, one sees that its summit's sharp ridge resembles a corner. It is probably this shape which gave its name to the hamlet underneath.

Even the angle of the mountain is cut by a fissure which crosses right through it [the angle]. This deep fissure deserves [H. II. 103] to be seen and even to be entered. It is tortuous and in some places so narrow that a man can hardly pass through it. If you have entered it, you will find places where the windings of the rock hide the sky, further away, the sky is only visible by fits and starts; elsewhere you see blocks of rocks inserted in the fissure, hanging above your head." [S. I. §. 236, pp. 182-183]

On his way from Contamine to Bonneville, Saussure observed:

"Finally, opposite Bonneville, the same escarpments at the bases of the Môle show a large opening which seems to be an empty space left by a mountain which collapsed in the past; its debris are still piled up underneath the opening. It even seems that this mountain was higher than its neighbors, judging from their layers which rise on the right and left against the empty space which the mountain left behind." [S. I. §. 440, p. 365]

"§. 493. Following the road of Servoz, we see on the left a continuation of rocky cliffs which crown the mountains above Passy. One of these rocks [H. II. 105] is so high, and at the same time so slender, that it is difficult to conceive that it would stay upright and withstand thunderstorms.

Near this high summit was once a mountain which collapsed in 1751 with a fracas so frightful, and with dust so thick that people believed it was the end of the world... [S. I. §. 493, pp. 413-414]

Hutton paraphrases Saussure: "Vitaliano Donati who was sent from Turin to examine this phenomenon, says in his letter, which M. de Saussure transcribes, that the great snows, which fell that year in Savoy, increasing the operation of some lakes, the waters of which continually undermined this mountain, occasioned the fall of three millions of cubic toises of rock. "

Hutton then states: "In describing the Salève, our author proceeds to mention other appearances equally conclusive with regard to the operations of water, but such as may be found over all the surface of the globe, to have been brought about by natural causes."

Saussure's description of caves in the Salève formed by water are cited next [no reference]:

"§. 225. The so-called caves of the Hermitage, or these 30- feet-deep excavations [H. II. 106] , 8 or 10 times as long, made by the total destruction of several layers of rocks, [Hutton has omitted the last sentence: "by what agent could they have been formed if not by the erosion of this ancient current?" This is obviously another reference to Saussure's débâcle.]

§. 226. The gorge of Monnetier itself, or this large fissure which separates the Grand Salève from the Petit, at the bottom of which is enclosed the beautiful valley of Monnetier, seems to have been formed by a similar current which flowed down from the Alps through the Arve valley to join our great river [Rhône] because the correspondence between the Grand and Petit Salève seems to indicate their past junction. We cannot understand what other agent could have detached and carried away this large patch missing at that place in the mountain." [S. I. §. 225, 226, pp. 165-166]

Hutton cites similar descriptions by Saussure in the Jura:

"The gable of the mountain, beaten by the wind and the rain from all sides, suffered the greatest changes: here, the layers were destroyed on the lakeside, exposing the summits of the opposite layers whose escarpments seem turned toward the lake; there, the layers [H. II. 107] were removed toward the valley of Mijoux, while the mountain on our side, with its regular slope toward us, shows escarpments toward this valley; still further, the entire gable was removed and there we notice depressions or gorges as at the Faucille, at St. Cergues, &.

The flanks and the base of the mountain were also damaged by torrents produced by rain and melted snow, which formed wide and deep excavations." [S. I. §. 335, pp. 273-274]

Hutton adds:

"Those ravages of time, or rather of the wasting operations of the surface of the earth, however great, compared with the little changes that we find in our experience, or in the most ancient record of our histories, are little things, considering the softness and solubility of the materials, and compared with the wasting of the Alps, which we find in tracing up those same rivers to their sources in the icy valleys."

Glaciers

In an almost poetic style, Hutton mentions [H. II. 107] that from the fertile valley of Chamonix, M. de Saussure will lead us up to the Montenvers, 954 fathoms above the sea. [H. II. 108] He insists that "It is to such a place as this that we should go to see the operations of the surface wasting the solid body of the globe, and to read the unmeasurable course of time that must have flowed during those amazing operations which the vulgar do not see, and which the learned seem to see without wonder !"

Hutton cites: [H. II. 109] "M. de Saussure, in his second volume of *Voyages dans les Alpes*, has given us a most interesting view of this scene, p. 6 ":

> "When climbing to the Montenvers, one has always underfoot a view of the valley of Chamonix , of the Arve river which waters the valley along its entire length, and of a great number of villages and hamlets surrounded by trees and well-cultivated fields. Upon arrival at the Montenvers, the scenery changes, and instead of a pleasant and fertile valley, we are almost at the edge of an abyss whose bottom is a much wider and extended valley filled with snow and ice, surrounded by huge mountains which surprise by their height and their shapes, and which frighten by their bareness and their escarpments." [S. II. §. 611, p. 6]

Hutton adds: "It is the cause of this appearance of deep valleys and colossal mountains, that I would now wish my readers to perceive. This is a thought which seldom strikes the mind of wondering spectators, viewing those lofty objects; they are occupied with what they see, and do not think how little what they see may have been, compared with what had been removed [H. II. 110] in the gradual operation of the globe. We have but to suppose this scene hewn out of the solid mass of country raised above the level of the valley; and, that this had been the case, must appear from the examination of all around.

Let us follow our author up those valleys between the solid granite mountains, valleys which properly are great rivers of ice moving, gradually but slowly, the ruins of those mountains upon which they are gathered. It is the Glacier des Bois upon which he is set out (p. 26)." [S. II. §. 630, 631, pp. 26-30]

> "After a good half hour of walking on the glacier, we crossed an ice ridge covered with earth, sand, and rock debris. I talked in the first chapter about these ridges parallel to the length of glaciers which are often seen in the middle of their width

or at more or less great distances from their edges. I showed that they were made by debris which from the top of the mountains had rolled down on the glacier and, like the glacier, were carried along by the ice on which they rest, follow an oblique direction, and descend at [H. II. 111] the same time toward the middle or the bottom of the valley....

Ten minutes later, we crossed a second ridge which was higher than the first one, and we guessed that underneath these debris the ice was 20 or 25 feet higher than in places where air and sunrays acted unhindered upon it. A third ridge occurs twenty minutes away from the second, and the fourth and last one follows very closely.

Here we are at the place where the glacier des Bois divides, as mentioned in §. 611, into two great branches, one turning right toward the Mont-Blanc, taking the name of glacier of *Tacul*, and the other left, named the glacier of *Léchaud*. It would certainly be more interesting to follow the one on the right to come closer to the Mont-Blanc; its snow-covered slopes which we see do not seem necessarily inaccessible. However these are misleading appearances. Indeed, glaciers cut by deep crevasses, hidden here and there by thin layers of snow defend [H. II.112] any approach of these forbidding mountains, unless, perhaps, choosing a year with much snow fall, and taking a time when this snow would still be solid, some adroit and courageous hunter might try to take this road.

Since such an enterprise is absolutely impossible at this time, we are following the left branch of the valley. After about a two-hour walk, we leave the glacier des Bois at the foot of the glacier of the Taléfre, namely, at the place where this glacier empties its ice into the glacier des Bois which has changed its name and is called here the glacier of *Léchaud*.

The sight of the glacier of Taléfre is here both majestic and frightening. Since its slope is extremely steep, its ice blocks press against each other, rise, and straighten up displaying towers and variously inclined pyramids which seem ready to crush the adventurous traveler who would dare to near that glacier.

To reach the summit of this glacier where it is less inclined and hence less uneven, we climb the rock which [H. II. 113] is on its left to the west. This rock is called the *Couvercle* [lid]; it is dominated by an inaccessible mountain peak which, according to the usage of the country, is decorated by the name of *needle* and, taking the name of the closest glacier, is called the *aiguille du Taléfre*.

The slope leading to the *Couvercle* is extremely steep; one follows a kind of groove excavated in the rock by nature. Some tips of rocks serve to hold on while climbing, as much by hand or even more by foot. These tips gave the name of *égralets*, or small steps, to this passage. It is nevertheless not dangerous because the rock, which is a very coherent granite, allows always a firm grip for both hands or feet. However, the steep slope makes it a little scary for the descent.

After having passed the *égralets*, we follow a slope which is much less steep. We walk either on the grass or on large slabs of granite and thus reach the edge of the *plan* of the glacier of Taléfre. The name of *plan* is given to a [H. II. 114] high and roughly horizontal part of the glacier where it can be crossed.

It had taken us an hour and a quarter to climb from the glacier of Léchaud to the plan of the glacier of Taléfre. We were tempted to rest for a moment before entering that glacier. Everything invited us to choose this place, a beautiful lawn watered by a brook which came out from underneath the snow and flowed its crystalline water on a silvery sand. What was even more appealing was a view of an extent and beauty whose description gives only a very weak idea.

§. 631. Indeed, how does one paint objects for the imagination which have nothing in common with the rest of the world; how does one transmit to the reader this impression mixed with admiration and terror inspired by these huge masses of ice surrounded and topped by even higher pyramidal rocks ; the contrast between the whiteness of the snow and the dark color of the rocks, wet by the waters distilled by these snows; the purity of the air, the glitter [H. II. 115] of the sunlight giving to all these objects an extraordinary clearness and vividness; the profound and majestic silence which reigns in these vast solitudes, a silence which is interrupted from time to time by the fracas of some large blocks of granite or ice which fall from the top of some mountain; and the bareness itself of these high rocks where one finds neither animals, shrubs, nor greenery. When one recalls the beautiful vegetation and the charming landscapes which we saw the days before, one is tempted to believe that we were suddenly transported into another world forgotten by nature, or on a comet in its aphelion. The view from the Montenvers gives only a very imperfect idea of the one from here. There, we see only one glacier whereas here we can see the three great glaciers des Bois, of Léchaud and of Tacul, without counting a great number of less important ones which, as the glacier of Taléfre, unload their ice into the principal glaciers. The countless rocks seen above these glaciers are all granite, [H. II. 116] because if there are, as I am sure, foliated rocks in between these granites, such as gneiss for instance, or hornstein; since they were softer than granite, their salient parts were destroyed by the injuries of the air, and only their bases remain, hidden at the bottom of the gorges which separate the high pyramids."

Contrary to his first reaction to the great scenery of glaciers, Hutton now returns to his theory as the main reason of his investigations, saying:

"This is a fact which, independent of the good authority we have here, we would have been naturally led, from the theory, to suppose. For in wearing out the solid mass, which had been once continuous among those mountains, something must have determined the situation of those valleys; but what so likely as some parts more destructible by the wasting operations of the surface than others, which are therefore less impaired, and remain more high." [H. II. 116]

Apparently little touched by the beauty of Alpine glaciers which he has never seen, Hutton concludes:" ...what we see remaining [of those solid masses] is but a specimen of what had been removed -- and that we actually see the operations [H. II. 117] by which that great work had been performed : we only need to join in our imagination that portion of time which, upon surest principles, we are forced to acknowledge in this view of present things."

Hutton's many citations of Saussure's next descriptions of the impressive Alpine summits in Chapter IX, [H. II. 311 to 329] shows his great interest, or is it obsession ?, since he cites page after page of Saussure's long descriptions of the *Aiguilles Rouges* and the Brévent [see §. 639, 640, 641, 642, 646 B, 646 C, 647, 648].

The origin of huge boulders of granite

In Chapter V, Hutton states: [H. II. 167] "Here are principles established, for the judging of a country, in some respects, from a specimen of its gravel or travelled stones."

As an example, he first cites the author of *Discours sur l'Histoire Naturelle de la Suisse* (A. Ch. Besson, 1780) who described some large boulders of granite between Orsières and Liddes, and at the pass of the Mont St. Bernard, wondering where they came from. [H. II. 169-171] Hutton then referred to Saussure as follows. [without citations in French. [H. II. p. 172]

"M. de Saussure has described a very curious appearance of this kind : It is the finding the travelled materials of Mont-Blanc, or fragments detached from the summit and centre of the Alps, in such places as give reason to conclude that they had passed through certain openings between the mountains of the Jura. This is a thing which he thinks could not happen according to the ordinary course of nature; he therefore ascribes this appearance to some vast *debacle*, or general flood, which [H. II. 173] had with great impetuosity transported all at once those heavy bodies, in the direction of that great current, through the defiles of the Alps, or the openings of those mountains.

In giving this beautiful example of the wasting and transporting operations of this earth, this naturalist overlooks the principles which I would wish to inculcate; and he considers the surface of the earth, in its present state, as being the same with that which had subsisted while those stones had been transported. Now, upon that supposition, the appearances are inexplicable; for, How [sic] transport those materials, for example, across the lake of Geneva ? But here is no occasion to have recourse to any extraordinary cause for this explanation; it must appear that all the intervening hollows, plains, and valleys had been worn away by means of the natural operations of the surface; consequently, that, in a former period of time, there had been a practicable course in a gradual declivity from the Alps to the place where those granite masses are found deposited. In that case, it will be allowed that there are natural means for the

transportation of those granite masses [H. II. 174] from the top of the Alps, by means of water and ice adhering to those masses of stone, at the same time perhaps that there were certain summits of mountains which interrupted this communication, such as the Jura, & through the openings of which ridges they had passed.

In this case of blocks of alpine stones upon the Jura, the question is concerning the transportation of those stones ; but in other cases, the question may be how those blocks were formed."

In Chapter VII, Hutton [H. II. 212] returns to the problem and gives another interpretation. [H. II. 218]:

"Let us now consider the height of the *Alps*, in general, to have been much greater than it is at present; and this is a supposition of which we have no reason to suspect the fallacy; for the wasted summits of those mountains attest its truth. There would then have been immense valleys of ice sliding down in all directions toward the lower country, and carrying large blocks of granite to a great distance, where they would be variously deposited, and many of them remain an object of admiration to after ages, conjecturing from whence, or how they came. Such are the great blocks of granite which now repose on the hills of Salève. M. de Saussure, who has examined them carefully, gives demonstration of the long time during which they have remained in their present place."

[Hutton's answer is actually pretty close to the explanation of the origin of large Alpine glaciers without visualizing as yet the Pleistocene extensive ice sheets of the northern hemisphere.]

The factor time

In Chapter VIII, *The present Form of the Surface of the Earth explained, with a View of the Operation of Time upon our land*, Hutton treats a subject which was not easy to explain by facts. Nevertheless, he tries to give some principles on that subject saying that [H. II. 238] "... the shepherd thinks of mountains, on which he feeds his flock, to have been always there, or since the beginning of things... But the man of scientific observation, who looks into the chain of physical events connected with the present state of things, sees great changes that have been made, and foresees a different state that must follow in time from the continued operation of that which actually is in nature."

He claims: [H. II. 240] "It is my business to generalise those facts and observations and to bring them in confirmation of a theory which is necessarily founded upon the decaying nature and perishing state of all that appears to us above the surface of the sea."

After having written many pages on this subject, he still remains without an answer. Among many naturalists, he cites Saussure only shortly, and only to explain his own ideas: [H. II. 248-249]

"M. de Saussure, who has so well observed every thing that can be perceived upon the surface of the earth, gives us the following remarks which are general to mountainous countries..."

> [S. II. §. 717, p.128] "§. 717... "In the upper part of the valleys, surrounded by high mountains, there are no rounded pebbles that are strangers to the valley where they are found. Those encountered there are merely debris of the neighboring mountains. On the contrary, in the plains and at the mouth of the valleys joining the plains, even rather high up on the slopes of the mountains which are adjacent to these plains, one finds pebbles and blocks that one could imagine to have fallen from the sky because they are very different from all those in the neighborhood."

[Saussure always stressed the interest of studying rounded pebbles from alluvial deposits in plains as the only remaining indicators of rock-types which existed in higher and far away upstream mountains that were destroyed by the processes of erosion.]

Hutton agrees: "Here are facts which can only be explained in supposing that the valleys have been hollowed out of the solid mass, by the gradual operation of the rivers. In that case stones travelled from a far, will be found at considerable heights, upon the sides of the valleys at their under end, or where, as our authors says, they terminate in plains." [H. II. 249]

The summits of the Alps and the pyramids of the Mont-Blanc

At the beginning of Chapter IX, *The Theory Illustrated, with a View of the Summits of the Alps*, Hutton says that after having considered the encroachment of the sea, he must examine "the height of the land above the level of the sea that is lowered." [H. II. 287]

He states: [H. II. 297] "In order to give a proper idea of this central part of the Alps, which is so interesting a part in the natural history of the earth, M. de Saussure, in the plates of his *Voyages dans les Alpes*, tom. 2. has given us two views, the one in profile, the other in face, of the Mont-Blanc. I have caused copy those plates, which are necessary to be consulted in reading the following description of this centre of the Alps.

[These two plates are, first, Hutton's Plate I, *Profil du Mont-Blanc et des Montagnes qui bordent l'Allée Blanche pris de la Vallée de Ferrez*, bound at the beginning of vol. II, and taken from Saussure's plate IV, vol. II, facing p. 302. Second, Hutton's plate II, *Le Mont-Blanc vu en face du côté de l'Allée Blanche*, bound at the end of vol. II, and taken from Saussure's plate V, vol. II, facing p. 326 (Figs. 2 and 3).]

Hutton says: "The author has taken much pains to form to himself a proper idea of the object which we have now in view; and he gives a description of the Mont-Blanc as seen from the top of the Cramont. It is that description which I am now to transcribe": [S. II. §. 910, 911, 912, 913, pp. 331-334].

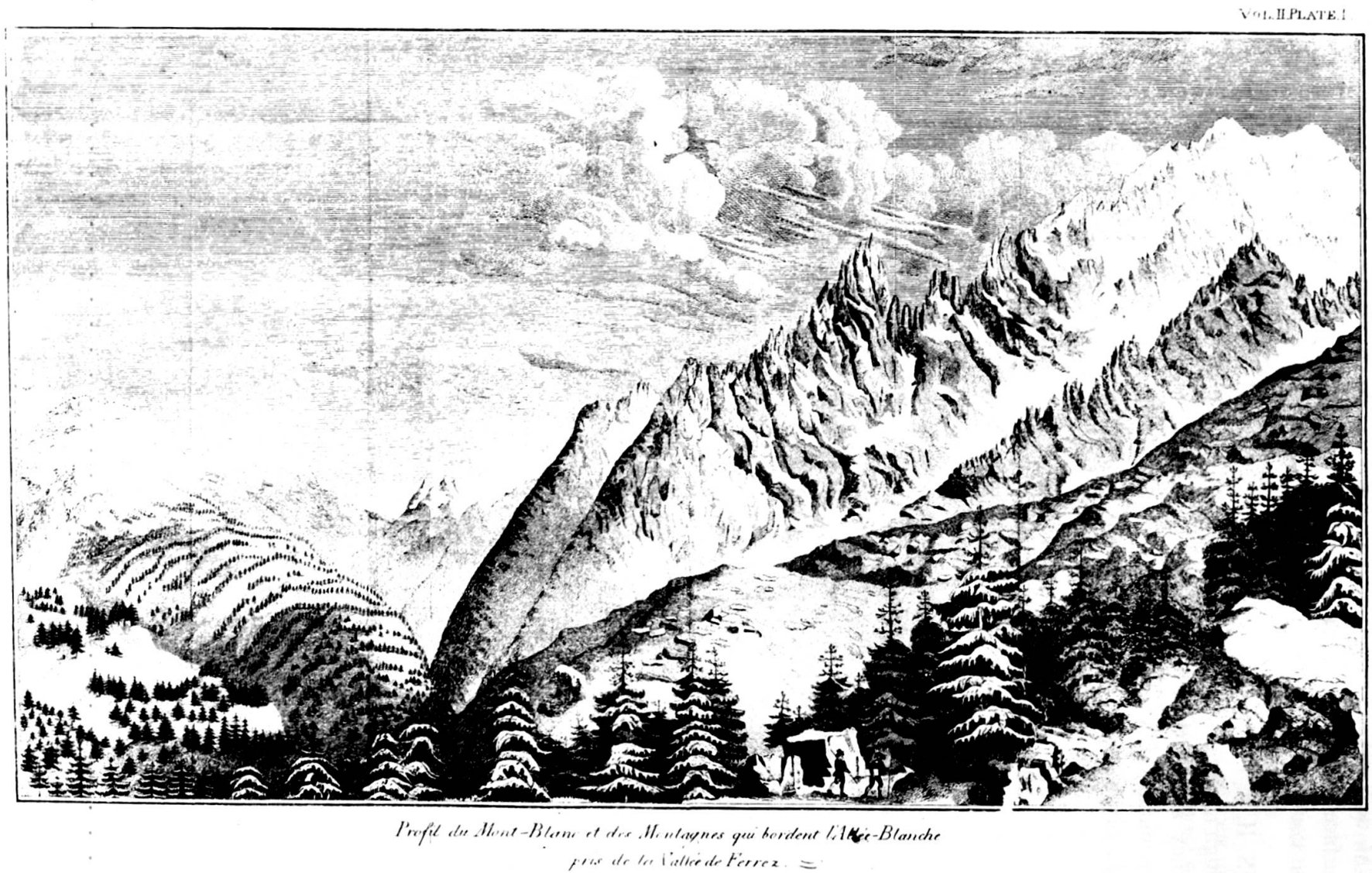

Fig. 2. Profil du Mont-Blanc et des Montagnes qui bordent l'Allée-Blanche, près de la Vallée de Ferrez. *Voyages dans les Alpes...*, Vol. II, 1786, Pl. IV, facing pages 302-303.

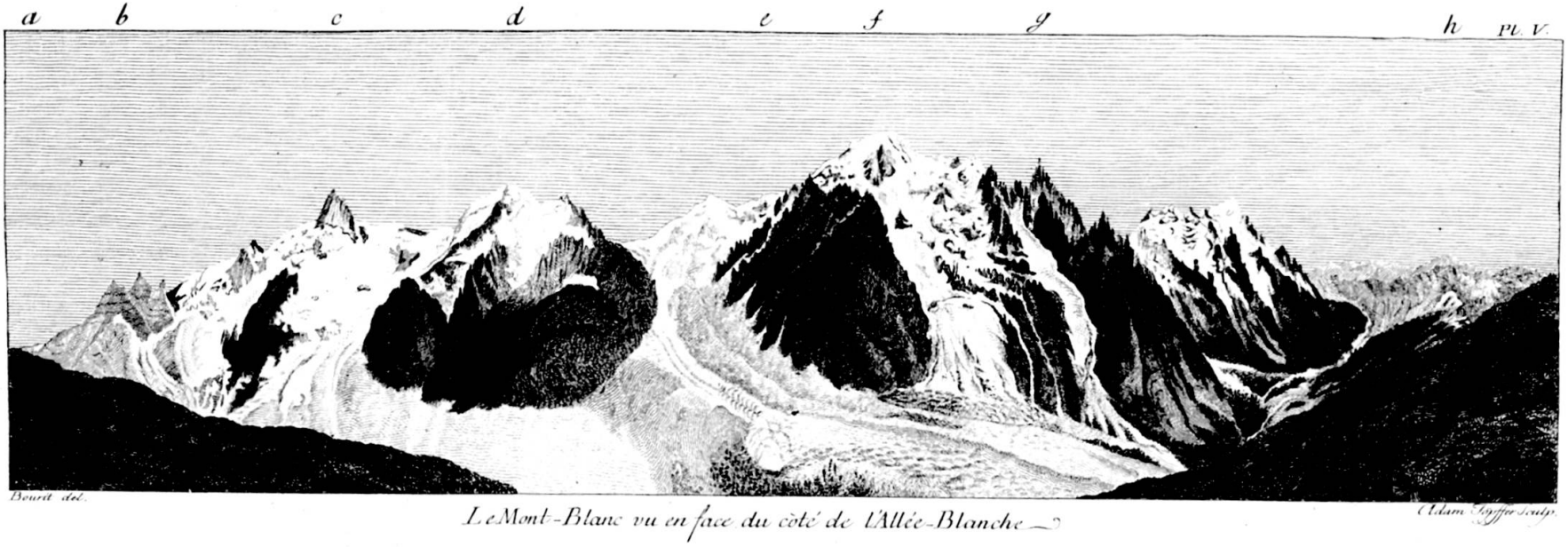

Fig. 3. Le Mont-Blanc, vu en face du côté de l'Allée-Blanche, *Voyages dans les Alpes...*, Vol. II, 1786, Pl. V, dessin de M. T. Bourrit d'après nature, facing pages 326-327. The letters a to h along the frame designate precise points of Saussure's descriptive text.

"§. 910. The first object of my study was the Mont-Blanc. It was there in [H. II. 298] its clearest and easiest way to be seen by an observer. It can be studied all at once, from its base to its peak; it seems to have cast off and flung upon its shoulders its coat of snow and ice to expose the structure of its body. Cut almost perpendicularly into a height of 1600 toises, snow and ice only settles in a few openings, thus showing everywhere the naked rock of which it is made.

Its shape seems to be that of a pyramid which displays one of its faces toward the SE and the Cramont. The right ridge of this pyramid on the SW side, rises to the summit at an angle of 23 to 24 degrees. The left ridge, rises to the same summit at an angle of 23 to 24 degrees so that the angle at the top is about 130 degrees.

The pyramid itself seems to consist of large triangular or pyramidal sheets. Three of these large sheets have their base in the Allée-Blanche and form [H. II. 299] together the entire front body of the base of the pyramid. Each one of these sheets, seen from the Allée-Blanche, looks like a high mountain; I described them in the last chapter under the names of Mont-Pétéret, Mont-Rouge, and Mont-Broglia, §. 830, 831, 834. However, from the top of the Cramont, their shape and their overall view appear more precise; for instance, we distinguish that they are themselves consisting of large pyramidal sheets; we see that injuries of time have destroyed the top of the Mont-Rouge whereas those of the two other pyramids remained intact.

These three sheets do not reach half the height of the Mont-Blanc; other smaller sheets, behind and above the three sheets, and placed on two principal lines which converge at the summit, finish to cover the face of this large pyramid. All these sheets have the shape of a pyramid, the smallest ones are the sharpest; I measured several whose angle at the summit was only 70 degrees. All, absolutely all, have their plane parallel [H. II. 300] to the Allée Blanche and consequently extend from NE to SW.

§. 911. With regard to the material of this large and high mountain, its entire peak and base, both at the center and north-eastward, are certainly granite; however the south-west side of the base, or the Mont-Broglia that we saw close-up, §. 834, consists of a rock that is softer and mixed with schorl, feldspar, and mica, as well as greasy quartz and pyrites.

From the top of the Cramont it is very easy to see that part of the base which is not granite. Its color is brown-reddish, the rock does not end by sharp and precise ridges and does not consist of large pyramidal slabs. They are nevertheless pyramidal sheets as the others, although small and pressed one against the other. The more they approach the summit, and thus the center proper of the mountain, the more they lose their red color, their angles become sharper, their slabs larger and smoother and finally, close to the summit, and at the summit itself, they are true granites perfectly characterized. It is thus possible to conclude that the [H. II. 301] whole body of the Mont-Blanc, and even its advanced bases which extend

toward Italy, consist of granite with the exception of the base of the exterior ridge toward the south-west.

§. 912. The mountain adjacent to the Mont-Blanc in the north-east which, seen from Geneva, represents somehow the first staircase when descending from the peak, is also composed of slabs of granite that seem to extend from the NE to the SW. However, the summit following this one, which forms the second staircase, seems to have some sheets surrounding its pyramidal body similar to the leaves of an artichoke as I described the *Aiguille du Midi*, Tome I, Pl. VI. Continuing further toward the NE, one recognizes the Jorasses which we saw from the top of the Taléfre, §. 637. From here, they seem to be, after the Mont-Blanc and its staircases, the highest peaks of the entire chain. They appear to result from the assemblage of several series of pyramidal sheets that converge toward their summit. In general, all the high peaks that are distinguished in this chain, from the [H. II. 302] Mont-Blanc to the col Ferret, are supported by ogives consisting of one or several series of pyramidal sheets leaning one against the other. The exterior ones have their bases at the bottom of the valley, and the interior ones rise gradually upward to the peaks. The two staircases of the Mont-Blanc are the only summits without ogives of this kind.

§. 913. The question now is : what could be the origin of these plane sheets and all these large and small pyramids that resulted from their assemblage, if not the remainders or the hardest cores of layers which resisted the destructions by weathering, whereas the intermediate parts, that connected them, were destroyed by these same processes.

But up to what point did crystallization contribute to determine these pyramidal shapes? Must one consider the Mont-Blanc, or any other of these needles, to be a huge crystal? [Hutton omitted the following crucial sentence by Saussure: "*or was it merely weathering that destroyed the softest parts and cut these pyramids mechanically ?* " [our underlining] I shall examine this theoretical question elsewhere. Presently, [H. II. 303] I shall be content to conclude that the southern face of the central chain of the Alps is, like the northern face of the same chain, made of layers of more or less vertical granite which extend mostly NE to SW."

Hutton confirms [H. II. 303] "This theoretical question of our author is so properly connected with the natural history which he has here given us, that it is not difficult to resolve it in the most satisfactory manner.

Here is an enormous mass of granite, the origin of which we are not now inquiring after, but the cause of its present form. The internal part of this granite subsists in a state of the most perfect solidity; the external again is evidently in a decaying state. This is a fact which we learn from the nature of feldspar, of which granite is in part composed; this crystallised substance is every where decomposed, where long exposed to the atmosphere. But it is not this gradual decay of the mass of granite perishing equably

from its external surface, and resolved into some of its components parts, that we are here to consider; [H. II. 304] it is only mentioned to show that the mass of granite is subject to decay, when exposed to the influence of the atmosphere, like every other compound mineral body, and to lose that perfect solidity which we find in the centre of the mass.

We find the granite masses not only subject to decay from the external surface, by the decomposition of the feldspar, or the dissolution of its constituent parts, but also liable to be separated into blocks of different degrees of regularity, commonly rectangular or approaching to the rhombic shape. This is the consequence, either of larger veins and fissures, filled with matter which is still more dissolvable than is the substance of granite, or else by imperceptible crevices or cutters, into which the atmospheric influences gradually insinuate, and form at last a visible separation.

In examining the tops of granite mountains, or where this rock is exposed to the weather, we may perceive those two species of decay proceeding together. The external surface of the stone, where there is a sufficient mixture of feldspar, is separating into grains [H. II. 305] which form a species of sand, being nothing but the particles of granite separating by means of the decaying sparry part. But a similar progress may be observed from the external surface penetrating in lines the mass of solid rock, and dividing that mass into the rectangular blocks into which those exposed places are gradually resolved.

He concludes that [H. II. 306] "It is impossible to see this series of pyramidal relics, without at the same time perceiving that manner of formation, by the gradual resolution of the solid mass of granite, as it comes to be exposed in succession to the influences of the atmosphere, which M. de Saussure has termed *les ravages du temps*."

From here on, Hutton no longer agrees with Saussure, saying that according to his theory, all the solid masses of the earth had consolidated by heat and fusion, so that we should find "*similar pyramidal mountains formed of different materials* [my underlining]. Now there is nothing more different than masses of lime-stone and those of granite. But pyramidal mountains are equally formed of those two different materials. In plate V, under the letter B, may be seen the calcareous pyramids which are near the *col de la Seigne*, and which in plate VI are represented under the letter C" (Fig. 4).

[Saussure's plate V is at the end of Hutton's vol. II, whereas Saussure's plate VI does not exist in Hutton's two volumes. It is in Saussure's vol. II, opposite p. 558, where the letter C shows the same calcareous pyramids in plate VI, named *L'Aiguille du Goûté, vue de Bionnassay*.]

In short, Hutton concludes that similar pyramidal mountains can consist of different materials, for instance limestone or granite. Therefore, there is no difference between primary and secondary mountains, a problem he had already mentioned before [H. II. 54].

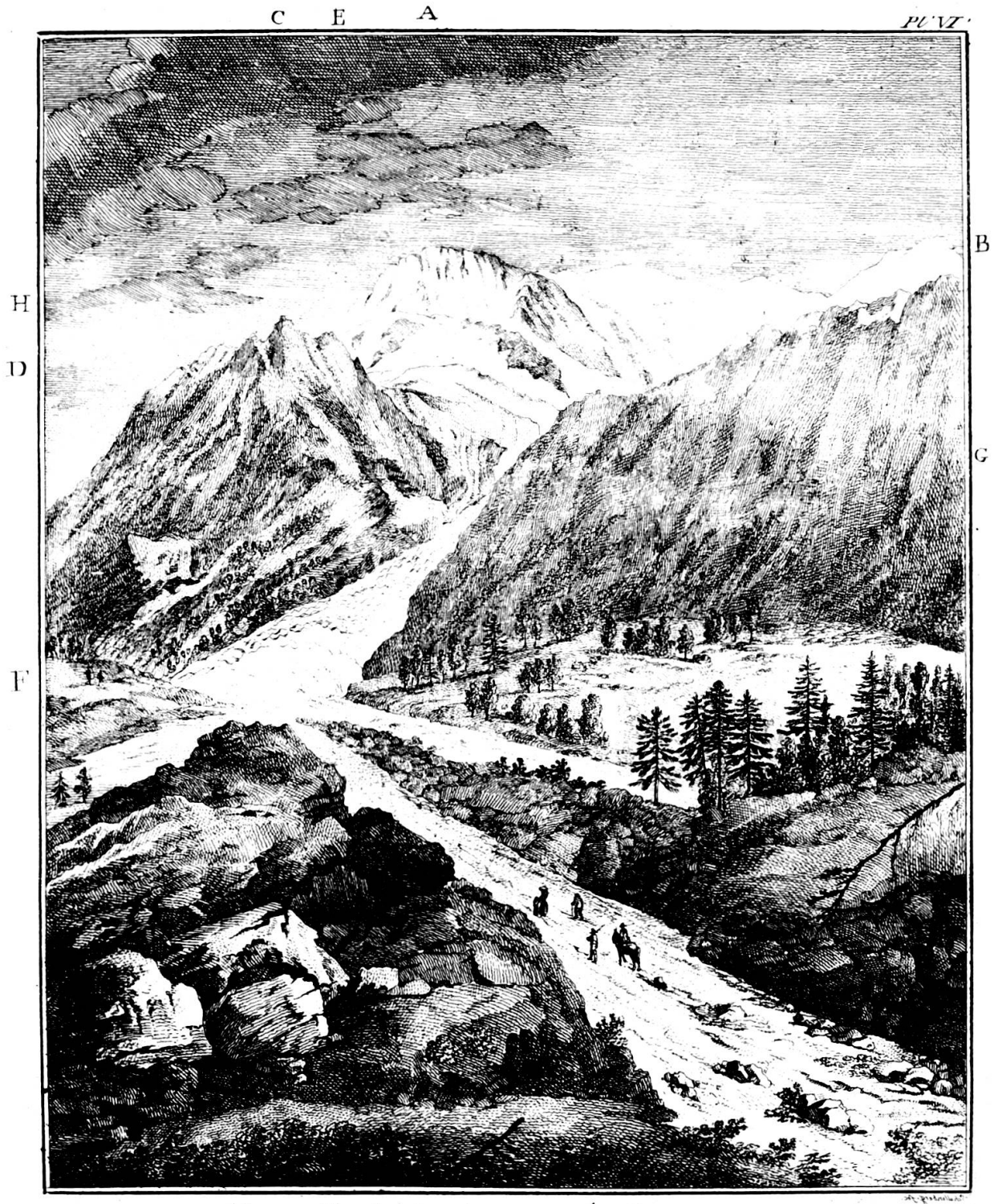

FIG. 4. L'Aiguille du Goûté, vue de Bionnassay. *Voyages dans les Alpes...*, Vol. II, 1786, Pl. VI, facing page 558. The letters A to H along the frame designate precise points of Saussure's descriptive text.

Conclusions on the summits of the Alps

Hutton states:" Here is a view of the summit of the Alps, from whence we may be allowed to draw the [H. II. 307] most important conclusions in favour of our theory. This summit is of solid granite, a mass in which there is no stratification, such as is to be perceived in all the other masses of those alpine regions."

Returning to those pyramidal mountains and their decay, Hutton reasons that [H. II. 310] "...there is a *ne plus ultra* of acuteness to which the *apex* of a pyramid would in time arrive; and that then the decaying summit would tumble by the lump alternately, and regain the acuteness of its point. Now, if this be the case, although we cannot see the process, which is too slow for human observation, we should actually find them in all the stages of this progress. But this is precisely the state in which the summits of those mountains are to be found. M. de Saussure gives a view of one of those pyramids, which will serve to illustrate this subject in the most perfect manner. It is from the Montenvers that this object is to be perceived."

He then gives the description of the Brévent by Saussure. [H. II. 311]

"§. 639. I have mentioned this mountain several times already. It is situated immediately above the priory [*prieuré*] of Chamonix on the north-west side. By its base it is linked to the *Aiguilles Rouges*, which were mentioned also in the first volume. However, its peak is bare, isolated, rounded on the backside , and cut perpendicularly on the side facing Chamonix. From all points of view, this mountain is one of the most interesting for a naturalist.

I climbed it for the first time in 1760 and I believe that no other naturalist had visited it before me. I returned there the following year [H. II. 312], and again in 1767, and finally a last time in 1781 to verify my former observations and to be able to give a more exact description of it.

§. 640. From the priory it is possible to reach the summit of the Brévent and return the same day. However, it is a laborious path because it takes at least five hours to climb, and the slope is extremely steep. Nevertheless, it is possible to do the first third of this climb by mule. Since I wanted to have time to observe everything carefully, I planned to spend two days there and stayed the first night in a chalet called *Planpraz*, which, counting from the priory, is at two-thirds of the total height of the mountain.

While climbing to Planpraz, one walks for two-thirds of the path on debris fallen and rolled down from the top of the Brévent. Even the hill on which the village of the priory is built consists of debris of that mountain. These debris emerged through a gorge that we cross when climbing. Spilling over to the left and the right, they took the shape of a cone in the middle of that gorge. Hills of this kind and shape are met very often in valleys surrounded by high mountains.

These debris, coming not only from the top of the Brévent, but also from its flanks and its base, are foliated rocks mixed with quartz, mica, and feldspar in every imaginable proportion. These different proportions lead to different degrees in hardness, from the hardest possible foliated granite to the softest micaceous rock.

§. 641. The rocks at the foot of which we pass before climbing the steep and grassy slope which reaches Planpraz consist of a rather hard foliated rock whose layers, parallel to the interior veins of the rock, follow the direction of the compass needle [magnetic N] and are very much tilted.

The chalet of Planpraz is in the middle of a pretty large meadow on a gentle slope toward [H. II. 314] the valley of Chamonix. It is dominated on the opposite side by bare rocks which form the summits of the chain of the Brévent. The edge of this meadow provides a very beautiful view of the Mont-Blanc, of the valley of Chamonix, and of the glaciers which join the valley. From the top of the Brévent, the same objects are seen with much greater clarity; nevertheless, for those who do not have the strength nor the courage to go as far as the top, the view from Planpraz is worth climbing to acquire at least some ideas.

Since I wanted to climb the Brévent the next day only, I spent the rest of the day observing the surroundings of the chalet. I examined with particular care rocks which were half a league to the north, above the chalet because, from a distance, they seemed to be colored red like several summits of this chain. This is the reason why the chain bears the name of *Aiguilles rouges*.

§. 642. I found out that these rocks were veined granites, mixed with quartz, feldspar, mica, and iron that colors the rock when decomposing at the surface. This color [H. II. 315] sometimes even penetrates far into the interior. The rocks are divided by well-recognizable layers, roughly vertical, and in the direction of the compass needle [magnetic N] as those I had observed below the chalet. They were cut by fissures, more or less perpendicular to their planes, mostly parallel to the horizon, so that these rocks are divided into large pieces of a roughly rhomboidal shape. Veins, even inside the rock, are also well-pronounced and exactly parallel to its layers. This general observation is of the greatest importance because it proves that these layers are really true layers and not only fissures produced randomly during contraction or by an uneven collapse of parts of the rocks. The veins are outlined on the white background of the rock by thin sheets of blackish mica. They are sometimes plane, sometimes wavy, but always regular and parallel between themselves except where they encounter some knots. Still they resume their direction after having [H. II. 316] bypassed the obstacle. Since mica occurs in small quantity, the rock is hard and breaks only with strong hammer blows. A close observation of the surface shows that the small sheets or blades of mica are always aligned in the direction of the veins of the rock. These same blades have almost no adherence among themselves so that the sheets which form the rock adhere to each other only at the places where no mica occurs.

§. 643. While observing this rock I asked myself whether it was possible that it was formed in this vertical position, whether these free blades could have attached themselves to these vertical walls, and whether the movement of the waters, clearly indicated by the foliated texture, would not have detached and dropped them gradually while they were being formed. I asked myself also if the fissures, which cut these sheets perpendicularly to their planes, could not date back to a time when these layers were horizontal, and could not have been produced by [H. II. 317] the weight and the uneven collapse of parts of the rock. However, to admit this speculation, one should explain how these beds, originally horizontal, could have straightened up, and why this straightening up was so frequent, so regular, etc. I shall reserve these important questions for some other time; however I do not believe it useless to stress the relationship these meticulous observations have with the theory [of the earth].

While making these reflections, I returned to the chalet of Planpraz where I slept on straw that I had spread close to the fire because the evening was extremely cool. [S. II. §. 639-643, pp. 39- 42]

§. 645. We started out on nice and gently ascending paths cut along large rocks resembling those I had observed the day before. Then we had the choice to go up either through somewhat tiresome slopes covered by debris of rocks, or through extremely steep grassy slopes. The latter appeared at first more pleasant and less arduous; however the grass was so dense and slippery that it became dangerous [H. II. 318], at least for people who are not accustomed to mountains. These rocky debris were those of foliated rocks similar to those we encountered when climbing from the priory to Planpraz. [S. II. §. 645, p. 44]

§. 646. B. After a one-hour walk we reached the foot of a rather steep and rocky cliff which had to be climbed to reach the summit of the mountain. It consists of a micaceous rock which, however, contains enough quartz to have some consistency. It separates into such clean-cut sheets that without using any tool, except my hands, I detached a slab measuring seven feet high, four feet wide, with barely one inch in its largest thickness.

From there I would have wished to go down to the foot of the large vertical slabs, which form the head of the Brévent, to look at them closely for a comparison between their base and their summit. However, from that place it was impossible because the slope is so steep that an average stone, which I put into movement, rolled at great speed, dragging along others, which in turn did the same, to [H. II. 319] form finally a torrent of rocks which rushed downwards with a thunderous noise, a thousand times echoed by the large rocks of the Brévent.

Since I could not descend, I went up through the regular passage which is some kind of channel or open chimney, leaning against an almost vertical rock, forty to fifty feet high. Many curious people had reached the foot of this passage without the courage to cross it. However, on my return I saw that at a half-quarter of a

league more to the north, one finds another extremely easy passage that leads to the same place and which one should therefore always prefer.

After having climbed this rock, we follow a gentle slope, without any danger nor fatigue, up to the summit of the Brévent.

§. 646. C. While ascending along the edge, on the side of Chamonix, I had a pleasure beyond words to see the magnificent slabs of granite forming the entire head of this mountain. Although the *blades* of the blackish mica mixed with this rock are parallel between themselves, making it somewhat similar [H. II. 320] to a foliated rock, the quantity of quartz and feldspar of which it consists, its extreme hardness, its small tendency to split in the direction of these sheets, places this rock, if not for the nomenclator, but at least for the naturalist, into the class of true granite; * and the [H. II. 321] perfect parallelism of these sheets with the faces of the large slabs, or the great divisions of the rock, shows that these slabs are layers and not parts that were separated by accidental fissures."

Saussure's footnote * says : [H. II. p. 320-321]

"The name of veined granite [*granite veiné*], which I believe to have used for the first time, was considered a very good choice by some naturalists whereas it displeased others profoundly. One of the latter claimed that what I called a veined granite was only a mass of granitic gravel, and hence some sort of coarse sandstone. But I would wish that those who truthfully could have believed that I committed such a blunder, and so frequently repeated it, would observe the granites of the Brévent. I would gladly send a sample to those among them who would like to receive one. Once they would have seen that the parts of quartz and feldspar in granite all have sharp and cutting angles, that these parts are intimately joined among themselves and glued together as in massive granite; that their coherence is as great as in massive granite; and that this rock differs only, as mentioned before, by the parallelism between themselves of rare blades of mica with which it is mixed, then, I am sure, these naturalists would recognize that this rock has all the essential characteristics of [H. II. 321] granite and thus must have the same origin, in short that it resembles true granite in the same way a foliated limestone resembles a true limestone in which blades cannot been distinguished. "
[End of footnote and continuation of Saussure's regular citation. [H. II. 321]

"The extreme regularity of these slabs completes the demonstration that these are true layers. Their planes, exposed here in a vertical height of over 500 feet, are perfectly continuous, as cut by the chisel, all oriented as the compass needle and with a verticality close to a few degrees, with which they lean against the body of the mountain. During the climb, it becomes increasingly clear that this structure is that of the entire mountain. One sees the sections of an infinity of layers; one passes over the tops of these vertical slabs and sees them extending in that same direction all through the mountain. I wonder if a naturalist who had seen the

overall view and these details [H. II. 322] could consider this mountain the product of randomly glued together grains of sand.

These slabs are cut somewhat obliquely to their plane by fissures, for the most part more or less horizontal, while others are very inclined. The rock is therefore very often cut into oblique-angle parallelepipeds. These same fissures emphasize an observation I made in 1776. When examining the vertical faces of the layers at the summit of the Brévent with good field glasses from a window of the priory, I had seen a great *dieze* clearly marked on the face of the mountain. In 1781, I saw it close up and recognized that it was formed by four of these fissures cutting each other obliquely.

§. 647. The top of the mountain is a blunted point, cut vertically on the side of the valley of Chamonix and rounded on all the other sides. This top is completely covered with debris and blocks piled up randomly. One is astonished to find these debris there because the peak is completely isolated [H. II. 323] and separated by wide and deep valleys from the summits which surpass it in height. It seems as if these debris could have fallen from the sky only; but when they are examined with care, we notice that they are of the same kind of rock as the mountain itself; and that all their angles are sharp, their faces plane and their shape often rhomboidal. This shows that the upper parts of the mountain, which are more exposed to weathering but not affected by rock masses above them, split up and break. Nevertheless, on the summit of the mountain I found a rock of a different kind; it was one consisting of black schorl in needles, of quartz and garnets; its shape was perfectly rhomboidal. But this kind of rock is found quite often in the veins in foliated rocks and veined granite. It is therefore probable that the vein to which this fragment belonged was destroyed together with the upper part of the rock, at least I could not find any trace of it in the solid part of the mountain.

The beautiful regularity of the layers of this high peak deserves the attention of amateurs of geology : the view alone would compensate for the trouble of climbing there.

§. 648. My principal goal during this first trip to the Brévent was to get a clear idea about the glaciers of the valley of Chamonix, of their shape, their position, and of the entire group of mountains where these glaciers are located. Since this mountain is situated approximately in the middle of the valley of Chamonix, opposite the Mont-Blanc and the glaciers which descend from there, it was certainly one of the best observatories that I could choose for that purpose. I climbed there on the most beautiful and clearest day. It was my first trip to the high Alps and I was not yet accustomed to the great spectacles so that this view impressed me so much that I could never forget it.

At the same time, and almost in one view, one observes from there six glaciers [H. II. 328] flowing into the valley of Chamonix and the inaccessible summits between which they originated; we see above all the Mont-Blanc appearing much taller and

much more majestic because seen from a higher place. We notice these immense stretches of snow and ice, whose brightness--in spite of the distance--seems almost unbearable to our eyes. These beautiful glaciers, flow out from them like as many solid rivers, travel between large forests of fir-trees, descend in tortuous sinuosities, and pour into the bottom of the valley of Chamonix. Our eyes, tired of the brightness of this snow and ice, find a delicious rest either on the forests, whose dark green contrasts with the whiteness of the ice crossing through them, or on the fertile and cheerful [*riante*] valley watered by the waters which flow from the glaciers." [S. II. §. 646 B., 646 C., 647, 648, pp. 49-53]

Hutton mentions :

"Our object at present is not to see the degradation of that great mass of granite out of which have been hewn, by the hand of time and influences of the atmosphere, these lofty pyramids which surround Mont-Blanc; it is to see the degradation of that immense mass of vertical or highly inclined strata, out of [H. II. 326] which that great mass of granite rises; and it is to understand the conical and rounded forms which are to be perceived more or less in all the inferior mountains, where apparently the degradation has come to a stand, and where the surface is actually employed in vegetation, or in maintaining the system of living bodies in this world.

How high those vertical strata may have been erected, or how much may have been wasted of that mass in forming the mountains and their valleys, is a question which is impossible to resolve : it is evident, however, that this quantity must have been very great."

Hutton is particularly interested in the Mont-Rose [This mountain has been called Monte-Rosa, Mon-Rosa, and Mont-Rose and I leave it as it was] where "one finds those strata at present in a horizontal position, as high as the summits of those granite pyramids that overlook the massif vertical strata which we are now considering; and in those mountains of Rosa, the valleys are most profound. It is therefore most reasonable to suppose, that the mass out of which the Brévent and all the other mountains had been formed, was once as high, at least, as the summit of Mont-Blanc." Hutton refers at length to the Mont-Rosa structure in Chapter X.

For the time being [H. II. 329] he confirms that causes which brought about changes to these high mountains were not violent ones because, although we "may often be witness to the action [the wasting of mountains],... it is only a small part of the whole progress that we may thus perceive, nevertheless it is equally satisfactory as if we saw the whole; for, throughout the whole of this long course, we may see some part of the mountain moving some part of the way. What more can we require ? Nothing but time. It is not any part of the process that will be disputed; but, after allowing all the parts, the whole will be denied; and, For what ? - only because we are not disposed to allow that quantity of time which the ablution of so much wasted mountain might require."

Horizontal strata in Monte-Rosa

In Chapter X, *The Theory illustrated with a view of the Valleys of the Alps*, Hutton mentions [H. II. 330]: "We are now to take a view of the valleys that are formed at the same time that the mountains are degraded." At first, he cites naturalists other than Saussure, in particular Besson (1780), one of the authors of the *Tableaux de la Suisse* who described the valley of the Rhône to the Great Saint-Bernard and the Gemmi, emphasizing the immense destruction in high mountains by rivers, the influence of the atmosphere over long periods of time, and the structure of the mountains on both sides of the Rhône. [H. II. 330-360]

Hutton adds at the end of these 30 pages of descriptions: [H. II. 360]

"Here is a most satisfactory view of the structure of this country on each side of the Rhône; strata of limestone and schisti, almost horizontal or little inclined, compose the mountains from their most lofty summits to the deepest bottom of those valleys. Such mountains cannot have been formed in any other manner than by the waste and degradation of their *horizontal strata* [my underlining] ; consequently here we are certain, that from the summit of the Gemmi to those upon the other side of the Rhône, all the solid substance had been hollowed out by water. Thus were formed the valleys of the Rhône, the Dala, and a multitude of others. [H. II. 361]

M. de Saussure has given us a description of a tract of alpine country of the same kind with that of the *Vallais* now considered, so far as the strata are here in a horizontal position, instead of that highly inclined situation in which those primary bodies are commonly found. It is the description of Mount-Rosa; Journal de Physique, Juillet 1790." [Saussure, 1790]

"Here the same interesting observations may be made with regard to the immense destruction which must necessarily have taken place, in the elevated mass of solid earth, by the dissolving or wearing power of running waters ; and this will be clearly explained by the formation of those mountains and valleys, which, while they correspond with mountains and valleys in general, *have something particular* [my underlining to be explained later on] that distinguishes them from most of the Alps, where the strata, being much inclined, give occasion to form ranges of peaks disposed in lines according to the directions of the inclined strata. Here on the contrary, there being no general inclination of the strata to direct the formation of the peaks, they are found without [H. II. 362] any such order. I shall give it in M. de Saussure's own words."

[Hutton's perusal of Saussure's article on the Monte-Rosa must have demanded quite an effort, first, to read it, because its print is rather small and dense, and second, to select among some hundred pages those of interest to Hutton : namely pp. 16-18. I have added Saussure's paragraphs as they appeared later in his Vol. IV: [S. IV. §. 2138-2139, pp. 350-352]

Hutton's citation:

§. 2138 "Indeed, all high summits I had seen until that day were either isolated like the Aetna or arranged in straight lines as the Mont-Blanc and its collateral peaks. But here I saw the Mont-Rose consisting of a suite of uninterrupted gigantic peaks, almost equal among themselves, forming a vast cirque, enclosing the village of Macugnaga, its hamlets, its pastures, the surrounding glaciers and the steep slopes which rise up to the peaks of these majestic giants.

But it is not only the singularity of the shape which renders this mountain remarkable but also, and even more, its structure. I have seen that the Mont-Blanc and all high summits of its chain consist of vertical layers. On the Mont-Rose, up to the highest peaks, everything is horizontal or inclined at the most at 30 degrees.

Finally, the Mont-Rose is different in the way it is made. It does not consist of [H. II. 363] massive granite as on the Mont-Blanc and the high peaks surrounding it; here are veined granites and foliated rocks of different kinds which make up the entire masse of this assemblage of mountains, from its bases to the highest peaks. It does not mean that massive granite cannot be found there, but it is purely accidental, in the form of nodules , veins, or layers interspersed with foliated rocks.

§. 2139. Therefore, we cannot say any longer that veined granite, gneiss, and other rocks of this kind, are only debris of granite assembled and glued together at the foot of the high mountains. Indeed, here we have rocks of this kind at more or less the same elevation as on the highest known granitic peaks where one would be very embarrassed to find the location of granite mountains whose debris could have served as materials, in particular if one considers the enormous mass of the entire walls of a cirque such as that of the Mont-Rose. Therefore, it would be an unacceptable hypothesis to assume an earlier existence of a mountain of granite in [H. II. 364] the present gap of the cirque and to believe that the cirque is the product of the debris of this mountain. Why would there be no remains of that mountain? It is easy to conceive that its top might have been destroyed, but its body, or at least the base, would have been protected by the debris of the top which would have been accumulated around it, so what could have destroyed it? Besides, the interior walls of the cirque, although with steep cliffs, are nevertheless not vertical; they advance from all sides toward the center; and the bottom, the center of the cirque itself, does not consist of granite, it is of the same material as its borders. Finally, we have recognized that the mountains which form the crown of the Mont-Rose extends outside over great distances so that the whole group of mountains is incomparably much larger than the mass which would have filled the interior gap of the cirque.

We must therefore admit, as shown by all the phenomena, that mountains of foliated rocks exist which consist of the same material as the granite and that they originated, as granite did, through the hands of nature [H. II. 365] without having themselves been granite."*

Hutton adds in a footnote:

* "M. de Saussure, upon the evidence before us, might have gone farther, and maintained that the masses of granite, which here traverse the strata in form of veins and irregular blocks, had been truly of a posterior formation. But this is a subject which we shall have afterwards to consider in a particular manner; and this example must be recollected." [This concerns probably chapter IV of Vol. III. (Hutton, 1899)]

Hutton said furthermore:

"Here is an example of the most interesting that can be imagined. Those mountains are the highest in Europe, and their lofty peaks are altogether inaccessible upon one side. They had all been formed of this same horizontal strata. How then have they become separate peaks ? and how have the valleys been hollowed out of this immense mass of elevated country ? – No otherwise than as we may perceive it upon every mountain, and after every flood. It is not often indeed, that in those alpine regions any considerable tract of country is to be found, where an example so convincing is exhibited. It is more common for those mountains of primary strata or schistus to rise up in ridges, which though divided into great pyramids, [H. II. 365] may still be perceived as connected in the direction of their erected strata. These last, although affording the most satisfactory view of that mineral operation by which land, formed and consolidated at the bottom of the sea, had been elevated and displaced, are not so proper to inform us of the amazing waste of those extremely consolidated bodies, *as are those where the strata have preserved their original horizontal position. It is in this last case, that there are data remaining for calculating the* minimum *of the waste* [my underlining. See below] that must have been made of those mountains, by the regular and long continued operations of the atmospheric elements upon the surface of this earth.

It is the singularity of these horizontal strata in that extensive alpine mass, which seems to have engaged M. de Saussure, who has inspected so much of those instructive countries, to make a tour around those mountains, and to give us a particular description of this interesting place. Now from this description, it is evident, that there is an immense mass of primary or alpine strata nearly in the horizontal position, which is common to all the [H. II. 367] strata at their original formation; that this horizontal mass had been raised into the highest place of land upon this globe, and that, in this high situation, it has suffered the greatest degradation, in being wasted by the hand of time, or operations of the elements employed in forming soil for plants, and procuring fertility for the use of animals."

[A few words seem necessary on this part of Hutton's theory. First, why did he cite at great length descriptions of the St. Bernard and the Gemmi by Besson, underlining that these mountains were, like the Rhône valley and the mountains on both sides of the Rhône, rather horizontal, or at least little inclined, and hence comparable to the structure of the Monte-Rosa which is horizontal ? In fact, Besson mentioned not only horizontal layers but also many vertical ones, as well as steep escarpments and otherwise vertical

rocks [H. II. 346, 351, and 356] among those mountains. It seems that Hutton might have gone a little too far to show a similarity between the horizontal layers of the Monte-Rosa and those in the Rhône valley and on both sides of that valley. With respect to the singularity of those horizontal layers, I believe that neither Saussure nor Hutton could have understood, at that time, that the apparent horizontal attitude of the metamorphic rocks of the Monte-Rosa massif represented, in fact, the gigantic Pennine recumbent folds, or nappes, which even on a regional scale simulate horizontal or weakly inclined beds.

However, Hutton's calculation of the *minimum* of the waste of mountains is quite interesting and perhaps one of Hutton's avant-garde traits. He has indeed figured out that only the structure of horizontal mountains could be used for such calculations, whereas vertical layers, or mountains, were unfit for such speculations because being vertical, the upper parts of layers would be destroyed without leaving any traces.]

[H. II. 369] Hutton then transports his reader to the other side of the Atlantic, "in order to perceive if the same system of rivers wearing mountains is to be found in that new world, as we have found it in the old."

After citing Thomas Jefferson's descriptions of the passage of the Potomac through the Blue Ridge, in his "Notes on Virginia" [H. II. 371-378], Hutton writes: "Thus both in what is called the Old World and the New, we shall be astonished in looking into the operations of time employing water to move the solid masses from their places, and to change the face of nature, on the earth, without defacing nature... [H. II. 378]

Hutton disproves Saussure's structurally controlled valleys

In Chapter XI, *Facts and Opinions concerning the Natural Construction of Mountains and Valleys*, Hutton is talking once more about the St. Gothard from where all the waters run in all directions. This time he needs to find out whether this mountainous country has been formed originally in its present shape, or has been excavated "by the constant operation of water running from the summit in all the different directions."

Hutton, apparently prefers the second answer and explains why: [H. II. 391]

"M. de Saussure, in his second volume of *Voyages dans les Alpes*, gives the strongest confirmation to the theory of gradual degradation of mountains by the means of rain: "

> "§. 920. I return to observations. There is an important one for the theory of the earth whose value is better appreciated from the top of the Cramont than from any other place; I want to talk about the famous observation by *Bourguet* (1729) on the correspondence of salient and reentrant angles [H. II. 392] in valleys. I already

talked about this in the first volume, §. 577, but I deferred to this chapter further developments I was going to give.

What had appeared very important in this observation was the belief that it might help to demonstrate that valleys were carved by sea currents at a time when the sea still covered the mountains, or that mountains bordering these valleys, were themselves formed by the accumulation of deposits along the margins of these same currents.

However, the study of valleys seen from the top of the Cramont shows clearly how little solid reasoning exists in these two hypotheses. Indeed, all the valleys viewed from the top of this peak are closed--at least at one of their extremities and some at their two extremities--by high mountain passes or even very high mountains : all are cut at right angles by other valleys, and finally one sees clearly [H. II. 393] that most of them were not carved by the sea but either at the time of the withdrawal of the waters [during the debacle] or by the waters from snow or rain. [Saussure's transversal valleys]

We first see the great valley of the Allée-Blanche which being parallel to the general direction in this part of the Alps belongs to valleys which I call *longitudinal* ; and we observe that this valley is blocked at one of its extremities by the Col de la Seigne, and at the other by the Col Ferret. Turning toward Italy, we perceive several valleys more or less parallel to this one, such as the valley of the Tuile and that of the Grand Saint Bernard which all abut, in their upper part, against some high mountain pass, or at the bottom against the Doire river where these valleys empty their waters opposite some mountains which correspond to them on the other side of this valley.

If we consider then this same valley of the Doire, which descends from Courmayeur to Yvrée, we see it blocked by the Mont-Blanc and the central chain which cut the river at a right angle in its upper part. [H. II. 394] Within seven or eight leagues, the same valley undergoes two or three very abrupt bends and is finally cut at right angles by several valleys emptying their waters into the river. These valleys are in turn cut by other valleys who are fed by their tributaries. If one ponders upon the width and extent of the ocean currents, is it possible to conceive that these narrow grooves, blocked and cut in a checkered pattern at very small distances, could have been carved by such currents ?

The observation of corresponding angles, whether universal or not, would be able to prove nothing more than this: valleys were either formed *by fissure and separation of mountains*, [our underlining] or, they were carved by torrents and rivers at present still flowing there. We observe the birth of a great number of valleys as I have shown at the Bonhomme, §. 767, on the flanks of a mountain. These rivers then become larger and deeper proportionally to the water flowing in them. A river flowing out from a glacier or a meadow, carves a [H. II. 395] groove, at first small, then becoming larger at the rate of increased water during their union with other springs or torrents.

> To become convinced of the truth of these facts, it is not even necessary to climb the Cramont. It is enough to look at any available map of the Pyrenees, the Apennines, the Alps, or any other mountain chain. There we see all the valleys outlined by the course of rivers; we notice that all the rivers and the valleys in which they flow end at one of their extremities at the summit of some mountain or some high mountain pass. The tortuous bends of a great river indicate a main valley into which flow other torrents or rivers, namely valleys of lesser importance, under angles roughly approaching a right angle. These rivers flowing from right and left into the main valley do not come in pairs at the same place of the river; they are like branches [H. II. 396] of a tree, implanted alternatively on its trunk. Hence, every little valley empties its water into the main valley opposite of a mountain. Moreover, we shall see also on the maps that even the largest valleys have almost all some necks forming locks [*écluses*], forks, and gorges.
>
> I do not pretend however that erosion by rain water, torrents, and rivers is the only cause of the formation of valleys: the tilting of layers forces us to accept another cause which I shall mention *elsewhere* [our underlining]. What I wanted to prove here is merely that the correspondence of angles, when occurring in valleys, does not prove that these valleys were formed by the currents of the sea." [S. II. §. 920, pp. 340-343]

The explanation "elsewhere", as Hutton found out, is Saussure's description of the *Val d'Aoste* (§. 960): [H. II. 396]

> "The mountains beyond Nuz, which border the valley toward the south, whose structure is very clear from here, consist of large layers resting one against the other and ending against sharp peaks [H. II. 397] with escarpments toward the south so that they turn their back toward the valley whose direction is always 10 degrees north-east. The mountains which we follow on our left are schists which also turn their back toward the valley while rising toward the north. I believe to be able to conclude that this valley is one of those whose formation is the same as that of the mountains themselves and not of erosion by currents of the sea or rivers. Valleys of this kind seem to have been formed by partial collapse of layers in the mountains which are in agreement with the direction of present valleys." [S. II, §. 960, pp. 396-397]

Hutton interrupts, saying [H. II. 397]: "Here I would beg to differ a little from this opinion of M. de Saussure, at least from the manner in which it is expressed; for perhaps at bottom our opinions upon this subject do not differ much.

M. de Saussure says that the formation of this valley depends upon the mountains themselves, and not upon the erosion of the rivers. I agree with our author, so far as the mountains may have here determined the shape and situation of the valley; but so far as this [H. II. 398] valley was hollowed out of the solid mass of our earth, there cannot be the least doubt that the proper agent was the running water of the rivers."

He adds after some wavering: "Besides, in supposing this valley original, and not formed by the erosion of the rivers, What [sic] effect should we ascribe to the transport of all those materials of the Alps, which it is demonstrable must have travelled through this valley ? Whether it is more reasonable to suppose, on the one hand, that the action and attrition of all the hard materials, running for millions of ages between those two mountains, had hollowed out that mass which originally intervened; or, on the other, that this valley had been originally formed in its present shape, while thousands of other valleys have been hollowed out of the solid mass?

But to put this question out of doubt, with regard to this very valley of the river Doire, M. de Saussure has given us the following decisive fact, §. 881: " [H. II. 399]

> "§. 881. Immediately above this spring is a rock which corresponds so exactly to another rock of the same nature, situated on the other side of the valley of Courmayeur, that one cannot doubt that they were formerly united [H. II. 400] with an intermediate mountain, and later destroyed by the ravages of time." [S. II. §. 881, p. 306]

Hutton adds: "Now, to see how little the situation of the strata influences the shape of the valleys, I shall transcribe the two paragraphs immediately following that which has given occasion to the present discussion":

> "A little beyond Nuz, the valley is no longer wide and plane as it was before in the surroundings of Aosta; it becomes narrow and very varied: here barren and wild, there covered with orchards and meadows watered by the Doire.
>
> §. 961. The mountain layers on our left, which after Aosta had constantly occurred on the east, rising toward the north, seem to have changed a quarter of league after the village Champave, a league and a quarter from Nuz. These layers rise at first toward the south-east, and a little farther straight to the south, whereas on the other side of the valley, they seem to rise toward the east." [S. II. §. 960, 961, p. 396]

[The difference between Hutton and Saussure is based on regional geology. For instance, Saussure's opinion is that in the Alps certain valleys were structurally controlled as well as naturally eroded by rivers. Indeed, there is ample evidence throughout Saussure's work of his understanding of river erosion. Hutton, however, relies on his knowledge of Scotland's old Caledonian chains where erosion had gone on for millions of years until there were no traces left of the initial structural control so that valleys would indeed appear as having "hollowed out that mass which originally intervened". In the Alps, however, the folding is relatively recent, the relief is of post-Pleistocene age, and hence the structural control is still visible in many instances.]

To end the debate, Hutton adds:

"In every mountain, and in every valley, the solid parts below have contributed in some manner to determine the shape of the surface of the earth; but in no place is the

original [H. II. 401] shape of the earth, such as it had first appeared above the sea, to be found. Every part of the land is wasted, even the tops of the mountains, over which no floods of water run, are degraded. But this wasting operation, which affects the solid rock upon the summit of the mountain, operates slowly in some places, compared with that which may be observed in others. Now it is in the valleys that this operation is so perceptible; and it is in the valley that there is such a quick succession of things as must strike the mind of any diligent observer; but this is the reason why we must conclude, that at least all the valleys are the operation of running water in the course of time...

[H. III. 402] But besides the general confirmation of mountains and valleys, there may be also in the forms of mountains, certain characters depending upon the species of substances or rocks of which they are composed, and the general manner in which those masses are wasted by the operation of the surface. Thus there is some character in the external appearance of a hill, a mountain, or a ridge of hills and mountains ; but this appearance is generally attended with various circumstances, or is so complicated in its nature, as to be always difficult to read ; and it is but seldom that it affords any very particular information ; although, after knowing all the state and circumstances of the case, I have always found the appearance most intelligible, and strictly corresponding with the general principle of atmospheric influence acting upon the particular structure of the earth below.

M. de Saussure has given us an observation of this kind, in describing the mountains through which the Rhône has made its way out of the Alps, at the bottom of the Vallée [Vallais]":

[citation H. II. 403] :

> "§. 1061. Further on, behind the village of *Juviana* or *Envionne* [Evionnaz], are rocks which have a shape I call *moutonnée* because we are tempted to give names to aspects that have no specific designation and which nevertheless have a distinct character. The mountains to which I apply this term consist of an association of rounded heads, sometimes covered with trees, but generally by grass or at the most by brush. These repeated and adjacent rounded forms give, as a whole, the aspect of a well-furnished fleece or of those wigs which are also called moutonnées [wavy and curly wigs very fashionable in the late 18th century]. The mountains which display such a shape are almost always primitive rocks or at least steatites, because I have never seen any mountain of limestone or slate with such an aspect. Such features which can provide some indication of the nature of mountains from a great distance by means of the vegetation which covers them are in small number and deserve to be studied and defined by appropriate terms." [S. II, §. 1061, pp. 512-513]

[Here is a rare agreement between Hutton and Saussure, namely, on the effect of atmospheric weathering on a particular rock structure. Saussure uses the term *moutonné* as a purely geomorphological tool to identify primitive mountains from a distance. The

term acquired its glaciological significance only in 1840 when Louis Agassiz discovered the Ice Age (Carozzi, A.V., 1996).]

Mountains on both sides of the lower Rhône valley consist of the same rocks

Still searching for facts to prove his theory that all valleys originated mainly from the carving of rivers, Hutton refers to Saussure's description of mountains through which the Rhône leaves the lower part of the Valais

Hutton cites Saussure as follows: [H. II. 419]

"The mountains I was going to observe above the meadows, which separate them from the road, consist of a mixture resembling the preceding ones very much. They are the last primitive rocks encountered [H. II. 420] when leaving the Alps through this valley. The village of Juviana, where primitive rocks occur on its backside, is still a league away from St. Maurice.

§. 1062. At the end of these rocks is a great gully, or rather a valley, which opens up from north to south. This valley, through which the torrent of St. Barthelemi flows, ends the primitive mountains I have just described; after them are limestone mountains. Nonetheless, the foot of the primitive mountain, cut by the torrent, remains wedged under the first layers of limestone mountains.

Through that valley, high snow-covered mountains are visible behind those which are adjacent to our road. The highest and most remarkable of these mountains is called the *Dent* or *Aiguille du Midi*. From the other side of the Rhône, we see another very high peak named *Dent* or *Aiguille de la Morcle*. These two high peaks have the same height, shape, and even the same very particular material. [H. II. 421] Both turn their escarpments toward the Rhône valley. Their crenelated peaks are brown. Underneath these brown peaks is, on both sides, a gray band which appears horizontal. Underneath this gray band, both rocks on either side turn yellow again. They are certainly secondary mountains; the gray bands seem to be limestone, and the yellow ones some argillaceous schist and sandstone, at least as far as we can judge from this distance because I have not seen them from close up. They also seem to be part of secondary mountains that trend behind the primitive ones which we observed on the banks of the Rhône. Although the yellow and gray bands seem horizontal, I have no doubts that the layers themselves, whose bands form sections, descend backwards, in rather steep slopes. The escarpments of these mountains provide a proof of this fact which is almost certain.

Were these high mountains in the past linked to each other by intermediate ones, [H. II. 422] of the same nature, covering both the primitive mountains that we observed and the entire valley where the Rhône flows today? I would be very careful not to affirm this question although I am tempted to believe that it was indeed so.

§. 1063. After the valley I just mentioned, which puts an end to primitive mountains toward the west, occur limestone mountains with thick and continuous layers. These layers rise against the primitive ones which we followed; the closest ones appear very tormented: here bent, there broken. After an interruption, these rocks are followed by other rocks, also limestones, cut vertically toward the side of the valley, and consisting of large horizontal layers. They are forming a semi-circular enclosure, almost joining those along the right bank of the Rhône, thus representing the entry of this valley whose river leaves only through a very narrow exit.

The city of St. Maurice is thus surrounded by this enclosure of rocks whose [H. II. 423] well-followed thick layers, separated by cordons of greenery, with an hermitage nestled between these layers, presents a particular and picturesque aspect.

§. 1064. The corresponding rocks on the other side of the Rhône, or on the right bank of this river, are also limestones. The mountain dominating this bank, a little above St. Maurice, consists of contorted and crumpled layers, bent in the strangest way. What is also remarkable is the fact that these bent layers have other layers on their side which are plane, almost vertical, and others underneath which are horizontal. A close examination of this strange rock should have been done to determine how, and up to what point, these layers are linked to each other before presenting any conjecture on their origin. Indeed, the valley is too wide to judge this situation with precision from one bank to the other.

We feel sorry that this wide valley is so little cultivated; it is almost everywhere [H. II. 424] covered by either marshes or debris from the adjacent mountains.

§. 1065. Before leaving this valley, let me give a general view of the bizarre suite of rocks which are part of the chain just observed:

The two extremities are limestones with the difference that the one closest to Martigny is mixed with mica, whereas that of St. Maurice is not. Between these limestones are enclosed rocks that are believed to be primitive; and in the middle of these rocks we find slates and puddingstones. It is known that the latter is usually classified among tertiary mountains, or with the most recent formation. However, these puddingstones here, which do not include any limestone and which are even not united by a limestone cement, were probably not posterior to the formation of limestone mountains, or at least they should not be confused with those sandstones and puddingstones of more recent origin as happens in the composition of mountains of the third order.

[H. II. 425] The slates, interposed among these sandstones and puddingstones, §. 1054, are of argillaceous nature and belong to the order of rocks called secondary. These slates, as well as all the rocks of these mountains, have vertical layers; but we saw that there is reason to believe that they were horizontal in the past." [S. II, §. 1062, 1063, 1064, 1065, pp. 513-516]

Hutton says: "It is singularly fortunate that such remarkable appearances, as are found in the rocks of this place, had called the attention of M. de Saussure to investigate a subject so interesting to the present theory; and it is upon this, as well as on many other occasions, that the value of those observations of natural history will appear. They are made by a person eminent for knowledge; and they are recorded with an accuracy and precision which leaves nothing more to be desired...

[H. II. 426] M. de Saussure found some singular masses, which attracted his attention, in examining the structure of the rocks on the left side of this little valley. Like a true philosopher, and accurate naturalist, he desired to compare what was to be observed on the other side of this valley of the Rhône, which he had found so singular and so interesting on that which he had examined. Accordingly, in Spring 1785, he made a journey for that purpose. In this survey he found the most perfect correspondence between the two sides of this valley, so far as rocks of the same individual species, and precisely in the same order, are found upon the one side and upon the other.

This author, after describing those particular appearances, sums up the evidence which arises from this comparison of the two sides of the valley; and he here gives an example of just reasoning, of accuracy, and impartiality, which independent of the subject, cannot be read without pleasure and approbation. [H. II. 427] But when it is considered, that here is a matter of the highest importance to the present theory, or to any other system of geology, no less than a demonstration that the rocks, of which the mountains on both sides of the valley of the Rhône are formed, are the same, and must have been originally continued in one mass, the following observations of our author will be most acceptable to every person who inclines to read upon this subject: "

> "§. 1079. This account shows that although the valley of the Rhône has in that itinerary an average width of almost a league, the mountains which surround it are usually of the same kind and in the same position on both sides.
>
> Nevertheless, there are three differences that I must talk about and evaluate in a few words.
>
> The most important difference is in the layers of limestone, §. 1073, that I found on the right bank but not on the left one. However, it is possible that they are there and that I missed them because they were hidden by debris or by other accidental causes; this assumption is [H. II. 428] all the more possible that these layers are only of a few feet thick. Besides, it happens often that veins, as appears to be the one I am talking about, does not extend over large distances although the nature of the mountain remains the same. Finally, what diminishes the importance of this difference is the fact that these limestone layers are close to slates which, like limestone, is said to be of the secondary order, and which alternates very frequently with slates.
>
> Another difference that could have been observed is that on the right bank, I did not find any pure petrosilex in large masses as on the left bank, close to the

cascade. However, this difference does not impress me very much either because instead of petrosilex, I found on the right bank rocks consisting, in very large parts, of feldspar. I do consider petrosilex and feldspar as stones of the same nature. Their hardness is more or less the same; so is their density and their fusibility. Chemical analysis demonstrates in [H. II. 429] both the same principles: siliceous earth, argillaceous earth, and iron; moreover, these ingredients are there in roughly the same proportions. The only difference is in the color and not in the aggregation of elements. It is known that such accidental qualities derive often from causes that are merely local.

The third difference, found in the direction of some of the layers, was mentioned before, §. 1075. It seem unnecessary to repeat that when layers, originally formed in a horizontal position, were straightened up by some violent operations of nature, we should not be astonished that these layers do not have the exact same position through the entire space which they occupy.

The differences are thus not very significant whereas the resemblances are, on the contrary, of the greatest weight. What gives them, in my opinion, the greatest strength is the rarity of stones which form these mountains: these porphyries based on petrosilex; these foliated rocks [H. II. 430] mixed with feldspar and mica. Furthermore, the correspondence in the order in which they follow each other; these beds of puddingstones separated by slates on both banks; and their position also more or less the same. These are the strong resemblances which permit us not to doubt that these mountains formed at the same time and by the same causes were linked in the past." [S. II §. 1079, pp. 523-525]

Hutton concludes: "Having thus shown, that the Rhône had in the course of time hollowed out its way from the central mountain of the *St. Gothard*, through the extensive valley of the *Vallais*, we may still further trace the marks of its operation in the more open country towards the lake. It is an observation which M. de Saussure made on his way from the valley of the Rhône to Geneva: "

"§. 1090. The main road from Bex to Villeneuve follows always the bottom of the Rhône valley, along the mountains which border upon the right or southern bank of this valley. These mountains consist in general of limestone, but at their foot [H. II. 431] we see until close to the city of Aigle--located a league and a half from Bex--the continuation of hills of gypsum enclosing saline springs...

§. 1091. On the other side of these hills, eastward of the main road, we observe the rising from the flat bottom of the valley of two hills which are elongated in the same direction as this valley. These hills are both limestone mountains with escarpments toward almost all sides. The hill closest to Bex, or more southern, is called *Charpigny*, the other *St. Tryphon*...

It seems obvious that these isolated rocks in the middle of this large valley have cores that are harder and more solid so they could resist the destructive causes

which carved this valley. They are nevertheless not exactly of the same nature and, above all, not of the same structure; the hill of *Saint Tryphon* consists of regular layers, either horizontal or more or less so, whereas that of *Charpigny* has very inclined layers which are often in great disarray." [S. II. §. 1090, 1091, pp. 539, 541]

Hutton concludes [H. II. 432] at the end of Chapter XI: "In M. de Saussure's Journey to the Alps, we have now seen a description of the shape that had been given to things, by those operations in which strata had been consolidated and elevated above the sea...

Chapters XII and XIII refer to examples "from the different Quarters of the Globe," followed by a summary of Hutton's doctrine. At the end of vol. II, [H. II. 567], Hutton says : ..."in pursuing this object [physical dissertation] I am next to examine facts, with regard to the mineralogical part of the theory, from which, perhaps, light may be thrown upon the subject; and to endeavor to answer objections, or solve difficulties, which may naturally occur from the consideration of particular appearances."

Hutton's conclusion to Vol. II seems to indicate that Hutton's goal was to continue his *Theory of the Earth*. However, it is unknown whether the discovered manuscripts of Volume III were actually meant to be published. We shall discuss next Hutton's comparison of Saussure's observations in the Alps with those of the granite mountains of Scotland.

Volume III

INTRODUCTION

Volume III consists of six chapters, entitled: IV. *Observations made in a Journey to the North Alpine part of Scotland in the year 1785;* V. *Observations made in a Journey to the South Alpine parts of Scotland in the year 1786;* VI. *A comparison of M. de Saussure's observation in the Alps with those made upon the granite mountains of Scotland;* VII. *The Theory confirmed by observations made upon the Pyrenean Mountains;* VIII. *An illustration of the Theory from the natural history of Calabria; VI. An Examination of the mineral history of the Island of Arran.*

My translation concerns only Chapter VI and follows the same rules as in Hutton's vols. I and II, with the difference of the abbreviations for Hutton which will be, for example: [H. III. 333]

A comparison of M. de Saussure's observations in the Alps with those made upon the granite mountains of Scotland

Hutton had long waited for the second volume by Saussure, published in 1786. After having judged it, he was disappointed that Saussure had so rarely described

junctions between granite and schistus in the Alps. "It is true," Hutton said, "that our author's view of this natural phenomenon is in some measure diametrically opposed to mine." [H. III. 92] He also mentioned--not in a very flattering way--"I think myself fortunate in having written the histories of my mineral [rock] observations before I had read the second volume in which those of M. de Saussure are recorded; for it will thus be seen what natural correspondancy there is to be observed between these mineral appearances of Scotland, in the history of which no influence of description had intervened, and those of the Alps, in the observation of which such different views of cosmogony had occupied the mind of the naturalist." [H. II 93-94]

Hutton was above all interested in "...the junction of the two different rocks and the manifestation of fluidity or fusion in the granite mass, from this body breaking and invading the alpine strata. M. de Saussure had in his description no such object in his view, but on the contrary, if there is any particular point to be ascertained, it is that of the stratification of granite in general, notwithstanding those appearances of masses in which no distinct mark of stratification appears."

[To understand the reaction of the two naturalists, we must refer again to the difference between their two countries. In the Alps, any unconformable junction between the Hercynian basement (granites and metamorphics) and the overlying Secondary rocks were mostly obliterated by the Tertiary main folding and compressional phase when overthrust planes took advantage of that particular zone of weakness. Ironically, the only "Huttonian angular unconformity" (comparable to Siccar Point, Scotland) between vertical Hercynian reddish metamorphics and horizontal Triassic sandstones, that Saussure could have seen, is at the summit of the Aiguilles Rouges which he did not visit. In short, while the geology of Scotland was only weakly affected by post-Caledonian orogenies, the Alps underwent their major overthrustings much later, during the Tertiary, in which all previous rocks were involved.]

In this chapter, Hutton [H. III. 102] had naturally chosen descriptions that were of interest to him, such as the foot of the Aiguille de Blaitière with the famous granitic pyramids. There Saussure had undertaken a trip to Chamonix to examine these pyramids, forming the highest needles of the central chain, from as close as possible. Here is Hutton's citation:

> [S. II. §. 660, pp. 67-70] "From this place I had a very extended view; however, what stroke me the most, namely, the center of my needle (pyramid), did not provide much satisfaction. The granite of which it is made--perfectly similar to the one I described above with respect to its composition (§. 659)-- showed no regularity in its structure: its fissures which divided them, went indifferently in all directions, here they appeared parallel; farther away, they were seen to converge and cut the rock into large cuneiform masses, elsewhere they were curved, cutting [H. III. 103] the rocks into parts, concave on one side and convex on the other. The only general fact that could be observed was the constant shape of the crevasses, which were always clear-cut, without indentations, without smears, so that the faces of the resulting blocks were always at least smooth, if not polished.

I descended the glacier on the opposite side to the one I had climbed, on a slope so steep that, if the snow had not been so hard, it would have been impossible not to be pulled down. The hat of Pierre Balme, my faithful guide, fell by accident and rolled all the way down on the edge of its rim. We were certain it was lost because it had to fall naturally into a large crevasse underneath of us. Nevertheless, it turned around it and escaped the danger with a lightness and a very unusul appearance of intent and skill.

§. 661. As soon as I came out of the glacier and the snow which extended still much lower, I searched for [H. III. 104] a place to rest and have something to eat. I found a comfortable seat on a grass spot at some higher place which provided a vast view of these debris which I had crossed that day. At first, my eyes neither discovered nor searched for anything interesting among these debris. However, when the rest and the diminution of the intensive cold, which had seized my legs during at least 2 hours, rendered some activity to my senses and my intention, I seemed to see some kind of regular shape in the chaos; I believed to see well-followed bands of rocks which rose their heads above the surface of these debris. The hope of making some interesting observation completed my well-being. I was in a hurry to get down there. My hopes were not dashed; I observed there a very rare and interesting fact, namely beds of granite enclosed between layers of foliated rocks. The highest was a perfectly regular and well characterized bed of massive granite [en masse]. Its overall [H. III. 105] uniform thickness was 12 to 15 feet. The layers that surrounded or enclosed this granite belonged to foliated granite, between 1 foot and two or three inches in thickness. These layers were perfectly regular and extended from NE to SW, as does the valley of Chamonix, [they are] in a vertical position. A little lower, was a second bed of granite, similar to the first, although less characterized, enclosed by layers which were no longer veined granite, but a quartzose and foliated white rock. The direction and the location both of the granite and the foliated rock was the same as the preceding ones. Below the second bed, I found a third one, and others yet down to the vertical layers I had crossed in the morning above Blaitiere (§. 658). But the farther away the beds were from the high needles [blades], the more they lost their granitic nature, approaching that of ordinary rocks mixed with [H. III. 106] quartz and mica with which they finally merged.

§. 662. These degradations and enclosures seem to show with the outmost evidence that granite had been formed exactly like foliated rocks. Indeed, how could one suppose that these beds or these thick granite layers, enclosed by layers of another rock, preserving the same thickness and following the same direction, could have another origin ? And if one adds to this consideration that of the nature of the rock itself, if one ponders about the veined granite which encloses the first of these beds and differs from the enclosed massive granite only by the arrangement of the blades of mica, which are confusedly dispersed in one, and arranged on parallel lines in the other; and that furthermore everything is similar between them, I must

admit that I cannot assume that they are bodies of absolutely different nature. Indeed, as I previously observed, [H. III. 107] we can very often notice in mountains of a different order, beds of massive rocks, such as limestone for example, in which we cannot perceive the slightest appearance of a foliated rock alternate with foliated layers, of the same kind or a different one. Nobody doubts that in spite of the difference in the textures, these beds and layers have had the same origin.

Furthermore, this difference in texture can be explained in a very natural way by the most generally adopted principles on the formation of mountains. Indeed, who could doubt that liquids of any kind, in which or with which mountains were formed, were not subjected to variations, that they did not carry here certain materials, and there others? These changes in movement and rest alone suffice to explain alternating massive and foliated rocks.

I am therefore convinced that the large masses of granite devoid of any traces of foliation or [H. III. 108] of regular divisions are nothing else but very thick layers that were deposited during intervals of stagnation of the fluid in which mountains were formed.

It even seems that the masses of these pyramids--of which we cannot know the thickness--are interspersed by beds of veined granite. Indeed, at the foot of these needles I have found everywhere numerous fragments of veined granite and of foliated rocks at heights where I could see above me nothing but massive granite. And these fragments could originate only from the middle of these same granits."

Hutton interrupts, stating [H. III. 109]:

"Here M. de Saussure inclines to make the central masses of the Alps to be of the same formation with those regular bodies of granite which he had found placed among the alpine strata. I am perfectly agreed with our author, only with this difference that I suppose those regularly formed granites to be of the same nature with the central mass ; this will require some explanation.

M. de Saussure supposed that he understands the formation of those granites which he found inclosed between the alpine strata ; consequently, it is by this means that he would explain the central masses, the formation of which he does not comprehend. I, again, suppose that I understand the formation of those irregular masses of granite ; it is by means of this knowledge that I am inclined to explain those regularly formed or apparently stratified granites, which I do not suppose to have been stratified originally along with the *granit feuilleté* with which they are inclosed. In the light in which M. de Saussure considered the subject, he had no distrust of those inclosed granites being strata ; consequently, it is possible that he may have neglected making some observation by which this question might have been absolutely decided. But it is probable that there was not enough of the solid strata seen to lead a person who had not this particular view in his head, to make a conclusion so very different from that which the first appearance must suggest.

[H. III. 110] In the present state of things, I am disposed to believe, that those apparently stratified granites were truly great veins interjected between the alpine strata; and therefore that they differ or, at least, in this respect from the stratified granite with which they are inclosed, while they perfectly agree with the granite mass of the pyramid or mountains, in having been produced at the same time or in a similar manner. "

[Geikie added in a footnote [H. III. 110] that "Hutton looked on the successive sheets of granite interposed among the schists as so many intrusive apophyses from the main body of that rock in the central part of the mountain."]

Hutton [H. III. 111] then returned to Saussure's description of the fourth pyramid: [S. II. §. 663, pp. 70-72]:

"§. 663. The following day, August 30, I started to examine the fourth pyramid, the closest to the *aiguille du midi* and named *aiguille du Plan*. To arrive at its foot, I took more toward the west than I had done the day before and in three quarters of an hour I passed in front of the chalet of the *Tapie* which was located in an extremely secluded bottom, at the foot of the glacier of the *Nantillons*, completely surrounded by debris of rocks which had been carried by that glacier.

At a good quarter of a league above the chalet, I passed near a small but rather deep lake, named *Lac du plan de l'aiguille*. Its water, although perfectly pure and limpid, appeared in the color of a green emerald. The temperature of the water in the shade, close to the surface, is 4 1/5 degrees, whereas that of the air is 7 1/5 degrees. The rocks along the western border of the lake consist of thin sheets, mixed with quartz and [H. III. 112] mica, running NE-SW and rising toward the NW. All those I crossed today have the same general trend (§. 656).

A little above the lake, one finds in the same foliated rock a bed of yellowish talc, soft to the touch, but mixed at times with quartz nodules.

§. 664. Leaving the lake behind on my left, and continuing to climb, I found beds that gradually resembled the nature of granite and finally a bed of true massive granite. These beds are most probably an extension of those I saw the day before (§. 661); at least, they run in the same direction and are intercalated like some of those mentioned before, between sheets of quartzose and micaceous rocks. Athough this bed is only two to three feet thick and does not preserve the same nature throughout its extension-- because, while trending toward the SW-- it changes into foliated rock. This is a remarkable characteristic of rocks formed by crystallization, and a very natural consequence of the nature of this [H. III. 113] process, to lack consistency of rocks which owe their origin to deposits.

Very close-by, I found beautiful pieces of specular iron attached to fragments of quartz.

Higher up, and still in the debris, I found a superb bed of massive granite, forty to fifty feet thick, hemmed in, on its upper side, by layers of massive granite, precisely of the same nature, and six inches to a foot thick. These beds are *vertical*

and oriented NE-SW as all the others of these mountains. Nevertheless, they are not of the same irregularity as those that precede them. Although they preserve well all along their extent the nature of granite, their divisions do not continue in a constant fashion over the entire length of the rock; here they disappear while two distinct beds join to form only one; there, new ones are formed by subdivision of one of them. This is still a natural effect of crystallization. However, what is most important to the question [H. III. 114] of the existence of layers is the fact that these divisions keep one and only direction.

From here to the needles all is granite, but so much covered that one only rarely sees the bottom of the soil. I found, nevertheless, at the foot of the needle itself, beautiful vertical sheets of massive granite of different thickness, from two inches to four feet, running NE-SW as all the layers in these mountains."

Hutton remarks:

"Here I do not see any evidence for the stratification of those masses of granite. M. de Saussure, in whose judgment we may confide, is clearly of opinion that they are not stratified in the usual manner, as having been formed by subsidence in water, but that they had been formed in a different manner. Therefore, I must still be inclined to suppose that it is the mountain or massy granite which is here injected among the alpine strata, and that this granite mass had only been stratified in flowing between those regular bodies. [H. III. 116]

Having after much pains arrived at the foot of the Aiguille du Midi, M. de Saussure thus continues his description."

"§. 674. I was well rewarded for my efforts, this rock is one of most extraordinary [H. II. 117] I have ever seen : a strange mixture of true massive granite with a heavy gray rock recalling hornstein which has no resemblance at all to granite and shows a rusty weathering color. Here is a bed of granite encased between layers of this rock, elsewhere, the same bed is in some places of granite and in others of this rock. Further on are transverse veins, elsewhere nodules of granite included in that same rock. Moreover, the rocky mass is divided into well-defined vertical beds, trending NE-SW. Only crystallization can explain such unusual mixtures. In a fluid containing in solution different matters which undergo crystallization, the smallest accident compels the elements of one of the materials to concentrate in great abundance in certain parts of the container : another accident changes this arrangement and forces the elements of the same kind to congregate at another place.

However, the entire needle is not composed of this singular mixture: the entire center and the [H. III. 118] upper part consist of beautiful pure granite, resembling that of the other needles. It is only this portion of its foot and that of the SW, which I see very distinctly, that appears to consist of these mixed rocks."

Hutton remarked: "The interesting fact, with regard to this valuable observation, consists in this, that there is a certain mixture or confusion of granite and the alpine

strata. It would have been still more interesting, indeed had M. de Saussure distinguished in this mixture which of the two different rocks was the containing and which the contained body; that is to say, which of those bodies had broken and invaded the other."

[H. III. 120] A footnote by Geikie explains :

[Among the phenomena attending the "granitisation" of rocks, or their absorption and transfusion by granitic magma, laminae, veins and nodular lumps of granitic material seem to be separately enclosed within the metamorphosed mass. De Saussure's observation was therefore no doubt accurate, but Hutton had not seen much of the phenomenon of extreme granitisation and did not realize how exceedingly complex the junctions of granite with the surrounding rocks sometimes are.]

Hutton then refers to Saussure's description of the other side of the central granite mass where granite "is found continuous with the alpine schisti."

"§. 860. This pass reaching 1195 toises [H. III. 121] above sea-level, according to my observation of the barometer, faces the *Col de la Seigne* and is located at the opposite end of the same valley. This valley continues to separate here the primitive central chain from the first secondary chains. There are indeed some mixtures, for instance, slates and limestones at the foot of these primitive mountains, and even at the entrance of some of their gorges, as one finds also here other primitive mountains behind the first line of the secondary ones. However, in general, the peaks on the right side are granitic and those on the left calcareous.

The general direction of the valley, following a straight line from the Col Ferret to the Col de la Seigne, is from NE-SW, but it curves in the middle where it becomes slightly convex toward the SE.

All the secondary mountains which limit the left - or SE side of this valley, have their inclined layers rising against the primitive chains. This situation can be seen distinctly from the top of the col and even better from slightly below. [H. III. 122].

The primitive chain does not show here a distinct organization. The Mont-Blanc is not visible, but is hidden by less elevated but closer peaks. The attention of the observer is attracted by two large glaciers flowing down from the primitive chain very close to the Col Ferret. The closest to this col is called the glacier of the *Mont Dolent*. Its highest plateau is a large cirque surrounded by high sheets of granite of pyramidal shape. The glacier flows from there through a gorge in which it becomes narrower. But as soon as it emerges, it opens up again in a fan-shaped manner. In summary, its shape is that of a sheaf, narrow in the middle and open at its two extremities. The second glacier is that of the *Triolet*, smaller and covered by debris of a high mountain of granite. About sixty years ago a considerable rockslide fell from the top of this mountain which, in one night, buried the chalet, located at the foot of this glacier, together with the cattle and the shepherds. Since then, these landslides have continued uninterruptedly. [H. III. 123]

These two glaciers are separated by a mountain called the *Mont-Ru*. It consists of granite, and as it seemed to me accessible toward its foot, I decided to examine it after having reached the bottom of the valley.

§ 861. The col Ferret itself consists of foliated sandstones and soft slates whose sheets move away from the vertical position only to lean against the primitive mountains. Their directions is toward the S-SW like that portion of the valley. These slates are intermingled with layers of quartz, either thick or thin, or whole here and decayed there in thousand different shapes.

§ 862. The descent is very steep, even dangerous for mules after rain, because the altered slates on which one walks form an extremely greasy and slippery surface. This slope, like the summit of the col, consists of slates and foliated sandstones, but one finds furthermore beds of a calcareous rock of a slaty color, while the latter rock builds alone the lowest part [H. III. 124] of the mountain on the side of the central chain. The layers of all these rocks have consistently the same structure as those on the top of the col....

§ 866. From the chalets I descended to the bottom of the valley, and from there, in order to observe the foot of the *Mont-Ru*, which separated the two glaciers (§ 813), I left the regular road and forded on my mule, not without some difficulties, the torrent which flows from the glacier of the *Mont-Dolent*. Having reached the foot of these rocks, I found them to consist of a granite whose structure I was unable to figure out. Upon close observation, I saw merely small fissures whose directions were not parallel among themselves. I saw the flank of the mountain facing the valley, coated in different places by a hard yellowish and foliated rock, whose surface trended S-SW as that portion of the valley. These sheets adhered to the granite but could be separated from it with a blow of the hammer. Upon close observation, they consisted of very thin sheets [H. III. 125] of a whitish quartz, separated by even thinner layers of yellow and shiny mica. This rock, when exposed to the flame of the blow-pipe, became covered by a shiny varnish produced by the vitrification of mica, whereas quartz remained white and intact. I can assume that these layers are the remains of a foliated rock which serves as a transition between slate or limestones of the secondary chain, and the granites of the primitive one."

Hutton states: [H. III. 125]

"All that is to be said with regard to these observations is this, that they are strictly conform to the supposition of the central body of granite having been forced up among the stratified schisti, in those operations by which land was raised from the bottom of the sea, and horizontal strata changed to positions nearly vertical. We shall now see what occurred to M. de Saussure upon considering the situation of the stratified alpine bodies. It is in continuing to describe those objects with which we are now more immediately concerned."

§ 867. After having made this observation, I returned to the large road which is [H. III. 126] nothing but a miserable footpath that, at the beginning, is rather rugged; the bottom of the valley is arid, covered with blocks of granite. The glacier of *Triolet*, buried underneath debris, a dirty and bubbly torrent emerging from heaps of ice and rubble, and some sickly-looking larches, scattered in the middle of these rocks and ice, present the saddest picture and awake only ideas of desolation and ruin.

§ 868. After having advanced a little along this road, and when turning backward to see the *Mont-Ru*, one can perceive some regularity in the structure of this mountain. It is divided from top to bottom by large fissures which cut through this mountain from one side to the other. These fissures, parallel among themselves, cut the mountain into large and very thick layers which are themselves subdivided into thinner ones. These fissures represent the cross sections of the intervals of large pyramidal sheets of which this mountain is composed. The most exterior sheets are not as well separated; their summits [H. III. 127] are poorly separated one from the other, and the whole picture of these summits form an almost continuous crest. However, the interior sheets which reach a great elevation, have their tops separated and form pointed and distinct teeth.

The planes of these sheets do not resemble those of the *Allée-Blanche*, which are parallel to the valley that runs here toward the SE whereas these planes run toward the S-SE, which makes a difference of about 34 degrees.

The following mountains in the direction to Courmayeur present an almost similar structure, however, the planes of the slices [H. III. 128] seem to gradually turn backward and take the direction of the valley, becoming finally parallel with it.

All these layers--if they are really layers--because I cannot really confirm it as I was able to do of those whose nature I clearly recognized, I mean all these sheets overhang the valley.

§. 869. Finally, when I say that the large beds of rocks are similar to those which are *overhanging*, one must not imagine that they have no support at all, they do lean on others, and although those are also overhanging, but gradually diminish in elevation, the mountain as a whole is supported and does not overhang : all is supported as in a vault.

§ 870. It would be very difficult to understand these anomalies that are visible in the situation of layers. Even in secondary mountains, as for example in the Jura, it is possible to see layers that are very close to each other in completely different positions. Primitive mountains [H. III, 129] that are much older and have therefore been exposed much longer to agents and revolutions of all kind, must necessarily present even greater anomalies. And if these mountains-- as I am beginning to believe-- have vertical layers, then this situation is due to violent movements which

uplifted layers that were horizontal at the beginning. It is more natural even that during this violent uplifting, the mountains of the same chain did not all take perfectly similar situations."

Hutton's answer is sweet and sour:

"Here M. de Saussure enters perfectly into my views, at least, so far as regards the formation of those alpine strata which have been considered by other philosophers as original bodies of the globe. This testimony, at all times most respectable, is on this occasion of the greater weight, in that upon the most mature consideration and accurate survey of the facts, M. de Saussure here changes his opinion, if he had allowed himself to form one, before examining sufficiently the subject." [H. III. 130]

Hutton returns to Saussure to "make the observations with regard to the granite better understood":

"§ 872 Walking through these pastures, with my eyes always fixed on the primitive chain, I saw beds at the bottom of this chain that were similar to slates and leaning against rocks of granite. Since in my opinion nothing is more interesting for the theory than the junctions between mountains of different orders, I decided to go and look at that one. But since it was too late to do a good job during that same day, I stayed overnight at Courmayeur, 2 leagues away from the junction, and I returned the next day.

From the bottom of the valley, it took almost three quarters [H. III. 131] of an hour of climbing to reach the point where the schists touched the granites. These schists, which from far away appeared only as a thin surface leaning against the foot of the mountain, are in fact a considerable mass of different layers. The material which forms most of these layers is remarkable by the fact that it makes a strong effervescence with acids and nevertheless melts very easily with the blow-pipe into light green and transparent glass which flows and collapses on the glass pipe on which it was welded. Its color is blackish and its grain resembles that of a calcareous rock...

The layers of these schists are intermixed with layers of a fine gray sandstone, weakly coherent, changing into a white sand which accumulates in great amounts at the foot of these same layers. The weak cement which unites these grains of sand is of calcareous nature.

These beds are a little arched, but their general situation--at least for those which are the lowest--is vertical or to a few degrees close, as they lean [H. III. 132] against the mountain. There can be no doubt on the situation of these beds of schists because they are exactly parallel to the sheets themselves of which they consist. But these layers are cut throughout and perpendicularly by fissures parallel to each other and which all curve in the same way while dipping toward the southwest under an angle of about 50°. These fissures leave between themselves intervals ranging from a foot to only a few inches. When these fissures are

observed from far away, it is impossible not to take them for the divisions of the layers of the rocks. This shows how important it is in this investigation to see closely and observe in detail because the internal structure of a rock alone can decide between these sections which intersect each other perpendicularly which one indicates the situation of the layers. I said previously what I thought of the origin of fissures cutting bedding and I shall return to that subject later on. [H. III. 133]

§ 873. I recognized in the transition of these schists to granites four well-marked nuances

The first layers of schists, where some weathering can be noticed, show sheets that are more wavy, more shiny, and more resembling mica, of which they have indeed the same properties.

The following ones are even more wavy; sheets of true mica can be recognized, and besides that a mixture of quartz that give sparks when struck with steel although the rock is always effervescent with acids. One can see in the same rock veins of black matter, shiny and consisting of small rhomboids, which seem to be the crystallization of the purest material of the schists; because these crystals dissolve with effervesce in acids without leaving any appreciable residue. Nevertheless they melt very easily under the blow-pipe into a transparent and greenish glass which collapses on the end of the glass pipe.

The third nuance is a true quartz [H. III. 134] mixed with some mica which does not effervesce.

The fourth is a gray granite with small grains of quartz, feldspar and mica.

This transition is generally of a rather small thickness. In some places, these four layers, taken together, are no more than one foot thick : however, granite reaches its perfection with clear and well-distinct grains only a few feet from this junction. The layers of this perfect granite are parallel to all those which form this transition.

At a rather great distance, while coasting along the mountain, I followed this junction of schists while sampling everywhere with a hammer the adjacent banks. I did not notice any appreciable difference in the nature of the beds which formed the transition between granite and schist. But I found a few changes in the position of the beds. Walking toward the SW, [H. III. 135] I saw the schists as well as the granites overhanging on the side of the valley, here at 35° and there at 47°. The direction of the beds changes also a little. Those which are closest to the Col Ferret trend S-SW, whereas those which are furthest away from the same col trend about 30° more to the west."

Hutton answers: "If I had not been acquainted with this subject of the junction of the granite and alpine schisti, I should have been inclined to think that here was an evidence of a gradation with regard to the original formation of those two bodies, when

these had been deposited in form of strata at the bottom of the sea. I am however almost persuaded from this description that the apparent gradations, here perceived, has for cause the contact of the granite in a fluid state of fusion with the schistus which it had been made to invade....

Upon the whole then, if it shall be allowed me to make this conjecture with regard to the observation of so able a naturalist, it would appear that here in the central granite of the Alps of Savoy and Switzerland, the same general fact is to be found which I have constantly observed wherever I could perceive the junction of the strata and granite masses; consequently that upon this occasion the body of granite in its present state is posterior to those invaded.

That this is truly the case, and that the granite really breaks and displaces natural strata of that alpine country, as well as those of Scotland, will appear from the facts which M. de Saussure relates in the former volume of his journey in the Alps. For there he gives an example, both in the Alps and at Lyon, of granite veins traversing [H. III. 137] the natural strata ... *[see below] Therefore, granite, in this particular place where it is mixed with the stratified bodies of the earth, is evidently of a posterior formation, and is the transfused body which had broken and invaded the regular strata."

* [Saussure's example in the Alps and in Lyon of veins of granite traversing schists is given in Chapter XII : "*Recherches ultérieures sur les Granits* ": [S. I. §. 597-601, pp. 530-535] Saussure describes debris of primitive rocks in the neighborhood of Vallorcine in a rich collection of rocks with fragments of granite fused together with schists (§. 598). The next paragraph (§. 599) mentions granite formed inside fissures of schists, giving the explanation of this phenomenon: infiltration of waters. Hutton, naturally, would not have mentioned this explanation and thus did not cite it. Saussure made a similar observation at Lyon, (§. 601) of a vein of granite, 21 inches large which cut layers of schists at an angle of 30°.]

Hutton continues: [H. III. 137]

"With regard to the stratification of granite in mass, I had formerly entertained the same idea with M. de Saussure, that they perhaps might be considered as stratified bodies of great thickness, consolidated by means of fusion. But since meeting with the most satisfactory evidence of granite having been made to flow in the manner of subterraneous lava, I have in some measure changed my opinion and am rather inclined to think that the apparent stratification, which may be: [H. III. 138] perceived in any of those granite masses, may be considered as a regular separation by the contraction of the mass."

Finally Hutton turns to Saussure's *resume*, in the last citation on the central masses of the Alps. [H. III. 139]

"§. 677. If one wants to gather all the observations presented in this chapter, it is necessary to consider that the mountains which border in the SE the valley of

Chamonix are composed of two distinct parts. One part is the uninterrupted and uniform massif which rises up to 7-800 toises above the valley (*first plate*) [facing p. 88 in Vol. I], the other consists of the pyramids or the isolated needles which tower above this massif.

The lower uniform masse consists of foliated rocks of different [H. III. 140] kinds, but mostly quartzose and micaceous. These rocks consist of very regular layers which run, as the valley, from NE to SW; these layers are not much inclined toward the foot of the mountain, but they rise gradually against the valley up to the summit where they are exactly vertical. These same layers approach the nature of granite the nearer they are to the summit of the mountain; and there they change into veined granites or even massive granite enclosed by layers of either veined granite or foliated rock.

The pyramids that tower above this massif consist of granite en masse. They are flanked, or even consist on the outside, of pyramidal leaves which are divided into large beds parallel to the planes of the leaves. The latter are almost vertical and are not rising against the valley as do the lower layers of the massif, but they lean against the pyramidal bodies themselves. Their direction is more or less the same as that of the massive layers. The center [H. III. 141] or the inner part of these pyramids, seem, in some places, to be without any regular structure and to be merely divided by accidental fissures.

Furthermore, one should not imagine that these pyramids are sitting on the massif that they dominate like a column on its base. The direction of the layers shows that the massif is leaning against the pyramids which have their own base and that it might rather be the massif which is partly sitting on the inner bases of the pyramids since the sheets of those descend toward this massif and seem to plunge underneath it."

Hutton's last answer: [H. III. 141]

"Here, in making a distinction of the central mass of granite and the erected strata of various species of alpine schisti, M. de Saussure has been at the utmost pains to inform himself that the central mass which is elevated to such a height, has its basis under those erected strata with which it is immediately connected. Now this could only happen in one of two ways; [H. III. 142] either the alpine schisti were superinduced upon the inclined granite in its present place; or the horizontal strata had been elevated by the rising granite. I suppose M. de Saussure's theory would lead him to conclude the first; mine again leads me to conclude the last."

CONCLUSION

Throughout this paper, we have encountered Hutton's great interest in Saussure's descriptions of the origin, structure, and composition of montains in general, and the Alps in particular. Why were those descriptions of such importance to him? The reason

was obviously related to the public reaction--mostly by Neptunists-- against his first *Theory of the Earth* of 1788. [See Hutton's Vol. I. pp. 201-268] under the heading *Kirwan's objections ...*] This theory had been largely based on Hutton's investigations in the Alpine regions of Scotland, whereas some of his critics were talking about the Alps and various other European mountains.

While Hutton had found reliable proofs for his theory in Scotland, he felt now that he had to compare the Alps--which he had never seen-- with the mountain regions in Scotland. Only then could he convince his critics and the world that his global theory was the one to accept.

Unfortunately, he was unable to travel during his last years and thus had to refer to Saussure's well-known descriptions in *Voyages dans les Alpes*. The reading of the first two volumes of that famous work became his major occupation. With relatively little time at his disposal to accomplish all the reading and restructuring of his last two volumes, I believe that he became more and more obsessed in his goal to convince his audience that his theory was entirely acceptable.

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[Hutton died before receiving Saussure's vols. III and IV.]

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