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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