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SULZER'S ANTIDILUVIALIST AND CATASTROPHIST THEORIES ON THE ORIGIN OF MOUNTAINS

BY

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ABSTRACT

Johann Georg Sulzer made several contributions to geology which deserve analysis. In 1746, he refuted Johann Jakob Scheuchzer's diluvial ideas on the origin of all mountains and proposed instead that large stratified mountains, deposited during numerous inundations, had emerged from the universal ocean due to centrifugal forces when the earth first started to rotate. Small mountains (stratified or not), consisting of debris of large mountains, originated much later during other inundations. Johann Gottlob Lehmann adopted many of Sulzer's ideas for the origin of his stratified mountains (Flötz-Gebürge) but retained the concept of a short general inundation. In 1762, Sulzer replied to explain specifically the origin of small mountains, namely of thick accumulations of loose or cemented pebbles, sand, plant and animal remains found in most flat countries. He proposed the concept of a catastrophic discharge of hanging lakes, located in large mountains, thus refuting once more diluvial theories or general marine inundations of short duration. After a last visit to the Alps, he confirmed in 1780 that some deep Alpine valleys such as the Urseren valley (today known as overdeepened glacial valleys with rocky thresholds) are the bottoms of ancient hanging lakes.

RÉSUMÉ

Johann Georg Sulzer a fait plusieurs contributions en géologie qui méritent d'être signalées. En 1746, il a critiqué les idées diluvialistes de Johann Jakob Scheuchzer sur l'origine de toutes les montagnes et il a proposé que les grandes montagnes stratifiées, déposées pendant de nombreuses inondations, sont sorties de l'océan universel par l'effet de la force centrifuge au moment de la première rotation de la terre. Les petites montagnes (stratifiées ou non), composées de fragments des grandes, se sont formées bien plus tard au cours d'autres inondations. Johann Gottlob Lehmann a adopté plusieurs idées de la théorie de Sulzer pour la formation de ses montagnes en couches (Flötz-Gebürge) en conservant toutefois le concept d'une inondation générale. Ceci a incité Sulzer a expliquer en particulier l'origine des petites montagnes, c'est-à-dire l'épaisse croûte de décombres, répandue presque dans tous les pays plats, composée de terre, de sable, de gravier, de pierres, mêlés à des restes de matières végétales ou animales. Il a proposé «l'éruption» successive de lacs suspendus dans les grandes montagnes, réfutant ainsi une fois de plus toute théorie de déluge ou d'inondation générale de courte durée (1762). Après un dernier voyage dans les Alpes, il a confirmé en 1780 son hypothèse de lacs suspendus en voyant certaines vallées alpines très profondes telles que la vallée d'Urseren (aujourd'hui considérées comme vallées glaciaires surcreusées à verrous) qui ont dû former dans le passé les fonds de ses lacs suspendus.

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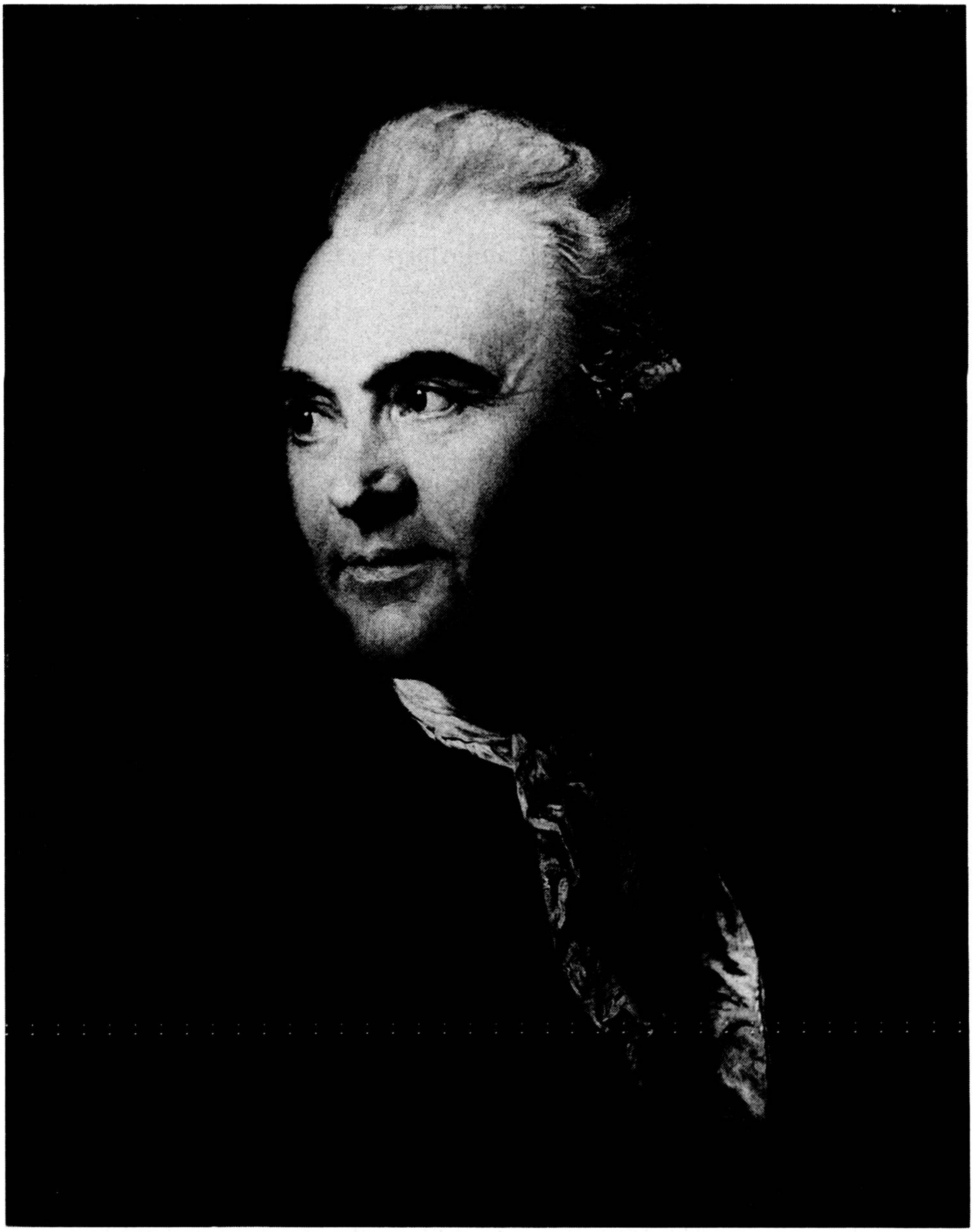

FIGURE 1.

Portrait of Johann Georg Sulzer. Oil painting on canvas, 57 × 48 cm (1771), by Anton Graff, at Kunstmuseum Winterthur. By permission of Swiss Institute for Art Research, Zurich.

INTRODUCTION

Sulzer (Figure 1) was born in 1720 in Winterthur near Zurich, Switzerland, where, after a dismal beginning in theology, he studied philosophy, mathematics, and natural sciences. In his autobiography, published posthumously, he declared with great honesty that all his life he had been an "Amphibium" (the German expression for Jack-of-all-trades) who felt at home among the wordly as well as among naturalists (1809, p. 16). Nevertheless, his reputation rests today solely on his studies on eighteenth-century aestetics. His work *Allgemeine Theorie der schönen Künste* appeared in many editions, was translated into many languages (including Russian), and was rendered easily accessible by a modern reprint (1771-1774, reprint 1970). Sulzer is also known today as educator, philosopher, and contributor to the *Supplément* of the *Encyclopédie.*[1]

There is ground for belief that Sulzer was considered an original thinker in his time. Even in the field of natural sciences, his contemporaries referred to him as the "famous professor Sulzer". Indeed, Paul Henri Tiry d'Holbach, in charge of articles in the earth sciences for Diderot's *Encyclopédie* (Schwab *et al.,* vol. 93, pp. 102-108; Naville, pp. 67-75), called Sulzer "ce savant naturaliste" (*Encyclopédie,* article "Terre, couches de la", 1765, vol. 16, p. 170) and mentioned his theory on the origin of mountains at great length in the article "Montagnes" (*Encyclopédie,* 1765, vol. 10, pp. 672-676). Lehmann referred to the "berühmte Professor Sultzer" (sic) in regard to the theory of the retreat of the sea (1756, p. 41). Elie Bertrand (1766, p. 115), the naturalist-pasteur at Bern, Switzerland, made remarks about the "notes curieuses" ("curieux" meant noteworthy and not bizarre in the eighteenth century) in Sulzer's translation of Scheuchzer's travels. Horace-Bénédict de Saussure called Sulzer "le célèbre littéraire de Berlin" who had made careful meteorological observations at Nice (1779-1796, vol. 3, p. 232). Finally, Nicolas Desmarest included Sulzer among forty authors who in some way had contributed to "géographie-physique", namely the science of the earth's interior and surface (1794-1795, vol. I, pp. 510-524).

This paper shall, therefore, analyze Sulzer's theory on the origin of mountains, mentioned by d'Holbach, in order to find out why it is today forgotten. The theory is included in footnotes to his translation of Johann Jakob Scheuchzer's travels in the Swiss Alps (*Naturgeschichte des Schweizerlandes, samt seinen Reisen über die*

[1] We consulted the following sources: *Biographie Universelle (Michaud) Ancienne et Moderne,* nouvelle édition, Paris, Imprimeur de l'Empereur, 1854, tome 40; *Dictionnaire historique & biographique de la Suisse,* tome 6, Neuchâtel, 1932; *Allgemeine Deutsche Biographie,* Berlin, Duncker & Humbolt, 1971, vol. 37; Kerslake, 1976; Sulzer's autobiography *Lebensbeschreibung,* 1809; Preface by Giorgio Tonelli to *Allgemeine Theorie der schönen Künste,* 1970, reprint, vol. I, pp. v-xix, including a list of Sulzer's works; *Verzeichniss der Abhandlungen der Königlich Preussischen Akademie der Wissenschaften von 1710-1870,* Berlin, 1871.

Schweizerische Gebürge, 1746, 2 vols) and in two essays added to this translation (Sulzer, 1746*a,* 1746*b* in Scheuchzer, 1746, vol. II).

We believe that Sulzer wrote his theory on the origin of mountains in order to refute Scheuchzer's diluvial ideas and that many of his seminal ideas were later adopted by Johann Gottlob Lehmann in his theory on the origin of Flötz-Gebürge (1756). Sulzer wrote that "large mountains" consisting today of folded and faulted layers of sandstones, limestones, and shales were deposited horizontally during numerous inundations in the universal ocean from which they emerged when the earth started to rotate. Some "small mountains" consisting of layers of earths and sand and others of massive accumulations of debris such as loose or cemented pebbles, sand, plant and animal remains distributed over the plains of Switzerland and even building a major portion of the Rigi were deposited much later by various inundations. D'Holbach mentioned Sulzer's first theory on the origin of mountains at great length but wrote that according to Sulzer all layered mountains ("montagnes par couches") were of recent origin thus confusing his large and small mountains. This misinterpretation of Sulzer's first theory certainly contributed to its later neglect.

At the very end of his theory, Sulzer had expressed the doubt whether the Deluge might have been one of the later inundations. Some twenty years later he found the answer and wrote in his essay of 1762 that neither the Deluge nor a general inundation of short duration could have accumulated all the debris found on land and in the sea and he proposed the concept of a catastrophic discharge of hanging lakes located in "large mountains" (1762, pp. 90-98). After his trip to the Swiss Alps and the Alpes-Maritimes in 1775-1776, he confirmed his latest theory and added some remarkable geological observations on inclined mountain layers (1781, German edition 1780).

SULZER'S EDITING OF SCHEUCHZER'S TRAVELS

It is obvious that Sulzer was more than just a translator. He proposed to call his editorial work a shortened translation, an abstract, an editorial revision of a manuscript (Scheuchzer, 1746, vol. II, Introduction, n. p.). Indeed, it is all of these things. In his preface to volume I of the translation of Scheuchzer's *Natur-Geschichte...* (1746), Sulzer explained that Scheuchzer had started his travels in the Swiss Mountains for the purpose of writing a general and systematic natural history of Switzerland. Since Scheuchzer was paid by the "high-ranking class in Zurich", he did not want to show himself ill-bred as if he did not want to fulfill his promise. He started, therefore, to publish a weekly magazine in 1705 where he mentioned the most noteworthy items encountered during his trips. The magazine entitled "Erzehlung seltsamer Natur-Geschichten des Schweizerlandes" was a success and he continued to publish it for two more years (Scheuchzer, 1746, vol. I, p. 11). In volume I, Sulzer translated from the Swiss German into High German Scheuchzer's colorful stories from the weekly magazines published in 1705, 1706, and 1707.

In the introduction to volume II, Sulzer stated that he was bringing to the German speaking reader Scheuchzer's nine travels because they had been published only in Latin (Scheuchzer, 1708*b*, 1723). He added some barometric tables by Scheuchzer and by himself, as well as some additional material by Scheuchzer. Sulzer shortened the Dutch edition of 1723 drastically, omitting Scheuchzer's botanical, historical, archeological, and political observations, pointing out that the book was treating only natural history and that whoever was interested in other subjects, mentioned in the Dutch edition, could find them in more up-to-date works, as for instance in Albrecht von Haller's work on botany. Sulzer deleted copper plates of Swiss cities from Merian's Topography which the Dutch editor had added to please the public, although they were not referred to in the text. Sulzer also honestly admitted that he had omitted a few copper plates by the author on the origin and course of Swiss rivers, asking the reader to refer to Scheuchzer's map of Switzerland which is essential to understand any one of the travels (Scheuchzer, 1712-1713).

In regard to content, Sulzer added many footnotes, sometimes to explain natural features to non-naturalists, and often to refute Scheuchzer's diluvial explanation of the origin of mountains and fossils. He said that with due respect to the author, he could not accept all his ideas. He added: "It does not mean that I have less respect for the author. In fact, I know only a thousand part of what he knew. I believe, as Bayle said in the introduction to his *Dictionnaire,* 'One may notice errors in books of famous men without overstepping the barriers of humility' " (Scheuchzer, 1746, vol. I, p. 14). The mentioning of Pierre Bayle's *Dictionnaire historique et critique* (1697) is often linked to "enlightened" or liberal thought; indeed, it has been called "the Bible of the eighteenth century and the great arsenal in the fight for religious liberties" (Fellows and Torrey, 1971, p. 79). It appears that Sulzer's upbringing might have influenced him. Indeed, he said in his autobiography that his father was an enemy of hypocrisy and religious enthusiasm and that he himself considered sermons boring (Sulzer, 1809, p. 11). It seems therefore quite possible that part of his motivation to translate Scheuchzer's travels was his desire to refute Scheuchzer's overpowering sermonizing in his explanation of the origin of mountains and fossils. Moreover, Sulzer felt the urge to explain certain features in the Swiss Alps which appeared puzzling to him and to many naturalists after him, namely the origin of large and small mountains.

SCHEUCHZER'S CONCEPT OF THE DELUGE

Scheuchzer was increasingly under the influence of the belief that fossil remains were proofs of the Deluge (the German word "Sündfluth" gives a better understanding of a flood brought about by the wrath of God because of the sins of men). At first, he was admitting that fossils were perhaps "figured stones" but after his

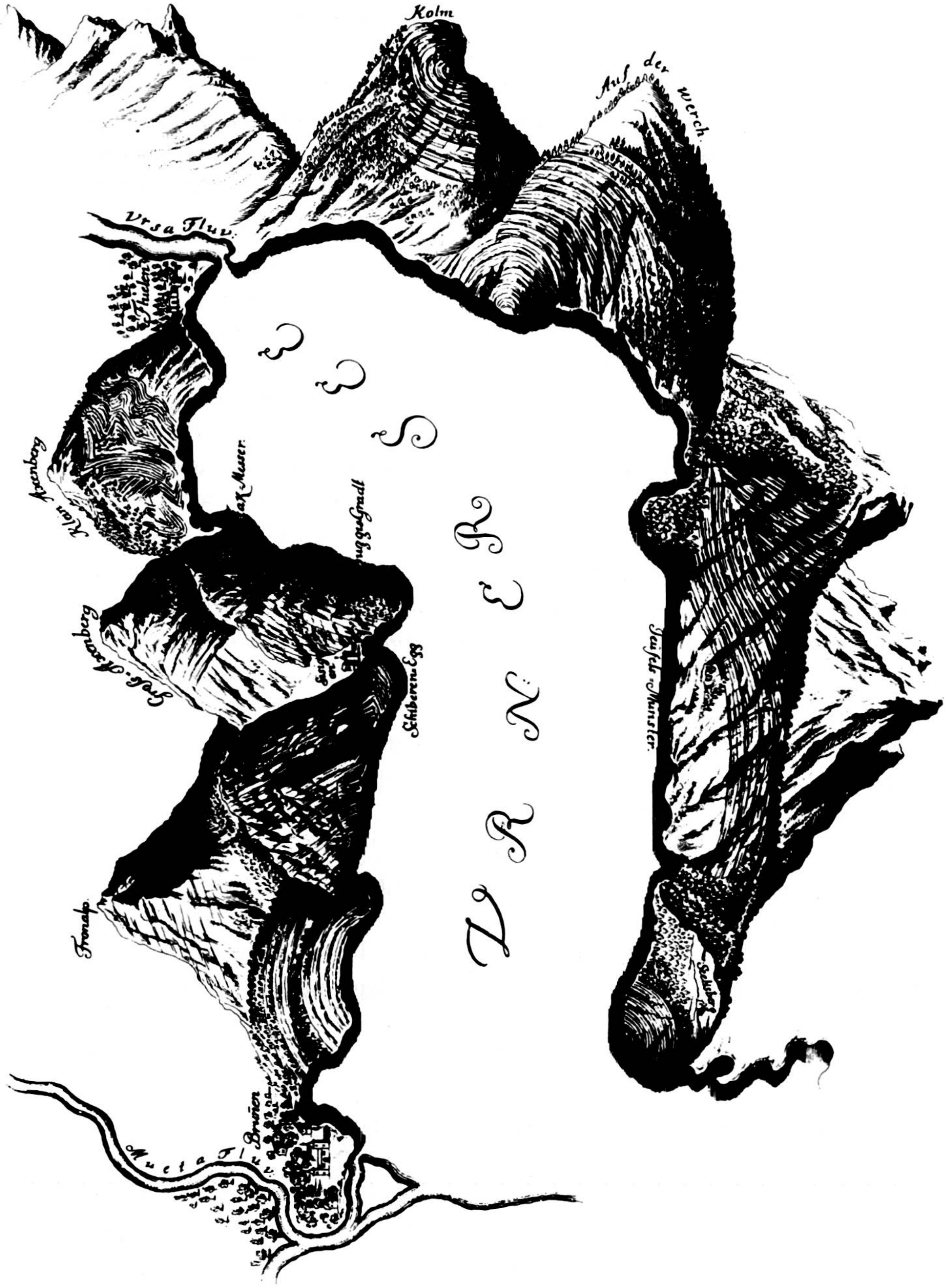

FIGURE 2.

Sketch of Uri Lake showing structure of surrounding mountains from Johann Jacob Scheuchzer *Helvetiae Stoicheiographia*... Zurich, 1716, Plate 1.

translation of Woodward's work in 1704 and his correspondence with the English diluvialist, he became convinced that they were indeed remains of animals, plants, and even men, buried during the Deluge (Jahn, 1969, pp. 192-213). Indeed, he presented to the learned his famous *Piscium Querelae et Vindiciae* (1708*a*) and in 1706, he started the printing of the weekly magazine "Erzehlung seltsamer Naturgeschichte..." (translated by Sulzer in 1746) where he sermoned his people that at the time of the Deluge, all earlier "mountains, stones, metals, minerals, earths, sand, vertebrates, trees, shrubs, plants together with men were crushed into a pulp or jelly". He told the world: "Come here, you despiser of the Holy Scriptures who believe that the story of the Deluge is simply a fable; come here and learn, you atheists, and the silent rocks will teach you, the hard mountains will render you soft, if you can still be bent"! (Scheuchzer, 1746, vol. I, pp. 131, 147).

Scheuchzer accepted Woodward's theory on the origin of mountains and said that during the Deluge the whole earth was in an almost liquid state and that most of the material settled thereafter according to their specific weight. The upper layers sank in certain places to form ocean basins; in other places, in particular in the Swiss mountains and other mountainous areas, some of the rock masses remained standing as pillars. He concluded that observation of the shape of mountains and of their regular separation into broken strata (Figure 2) demonstrates that initially horizontal layers broke and collapsed (1746, vol. I, pp. 132-136).[2] In short, according to Scheuchzer, all mountains were formed during the Deluge as proven by their layers and the presence of fossils.

SULZER'S THEORY ON THE ORIGIN OF LARGE AND SMALL MOUNTAINS

Sulzer's theory was based on three fundamental observations.

1. In response to Scheuchzer's opinion that only a few naturalists believe that mountains were formed by various causes at different times (1746, vol. I, pp. 122-123), Sulzer added the following footnote:

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[2] In the work *Helvetiae Stoicheiographia*... (1716-1718), instead of believing in a collapse of layered mountains, Scheuchzer stated that at the end of the Deluge, God gave orders to break and lift the upper layers of the earth-crust, like egg-shells, thus creating mountains and valleys (1716, pp. 109-110). Sulzer did not translate this work because it was already written in German. It contains mostly geographical, mineralogical, and meteorological details of Switzerland and it is, therefore, all the more surprising to find there an unusually precise description of highly folded beds in mountains along the Uri Lake (1716, pp. 111-115) followed by an even more spectacular drawing of the variously shaped and inclined layers in these mountains (the map follows p. 168). It is noteworthy that Scheuchzer's first travel undertaken in 1702 with his brother Johann includes no such description. He merely mentioned that on his boat-trip from Brunnen to Fluelen he saw such and such mountains (see *Natur-Geschichte...*, 1746, vol. II, pp. 1-8). In *Helvetiae Stoicheiographia...*, however, he mentioned his brother Johann's essay "De structura montium" sent to the Royal Academy of Sciences at Paris (p. 111). It has been established (we are indebted to William B. Ashworth Jr., Linda Hall Library, Kansas City, Missouri, for this information) that Johann Scheuchzer was indeed the author of the map and, therefore, of the first illustration of folded mountains in Switzerland (see Koch, 1952).

Since the author treats this subject with such scorn, I am not ashamed to say my opinion on the origin of mountains, in particular that mountains were not formed all at once, nor in the same fashion. It is obvious that mountains were formed little by little during several inundations as proven by their layers. Some mountains display alternating thick and thin rock-layers although stones are of the same kind in each layer. This could not have happened if all layers had been transported at the same time to the place where they now occur. Indeed, they would have formed only one layer. Therefore, several inundatio ns must have occurred, namely as many as there are layers of the same rocks in a mountain. In this manner the mountain increased in height (footnote in Scheuchzer, 1746, vol. I, p. 123).

2. Having spent some time as supervisor of archeological digging between the villages of Lunnern and Maschwanden, in the county of Knonau, Zurich (not far away from the Reuss river), he observed horizontal layers of potter's clay interbedded with sand layers. He noticed that the thicker a layer of clay, the more sand is present beneath "which clearly proves that various inundations occurred" (footnote in Scheuchzer, 1746, vol. I, p. 123).[3]

3. During a trip undertaken in 1742 to various mountains in Switzerland, he was impressed by an agglomeration of cemented stones at the very summit of the Rigi Mountain which he called "natural walls" because they consist of various pebbles cemented together by a sandy material which resemble man-made walls. The stones of these walls, he said, consist of many polished or abraded stones of various kinds which are normally found separately along the banks of rivers. Therefore, they must have been torn away from other mountains, their place of origin, and transported to this mountain top. Since he found underneath these walls the so-called "Geissberger-Stein or *Sax. quarzosum album nigra maculatum,*[4] he said that "there is no doubt that the lower part of the mountain on which these transported stones rest was already hard during inundations, otherwise all materials would have become mixed together" (Sulzer, 1746*a*, pp. 36-37).

Based on these three observations, Sulzer wrote his essay, entitled "Untersuchung von dem Ursprung der Berge..." (1746*b*). He gave six principles on which the explanation of the origin of mountains must rest. 1. The earth was once in a liquid or at least in a very soft state. This principle is based on Newton's hydrostatic laws, on Steno's opinion that earth- and rock-layers were formed while in a liquid state, and on the fact that fossil remains are included in these layers (1746*b*, § 17)[5].

[3] River flood deposits consist for each flood of a basal layer of bed load sand overlain by a layer of suspension clay with individual thicknesses directly proportional to the intensity of each particular flood.

[4] Geissberger-Stein is the name in Swiss German for granite (see Charpentier, 1841, p. 242).

[5] Page numbers shall be replaced by paragraph symbols (§) for Sulzer's theory on the origin of mountains.

2. Water formerly covered the highest mountains when these were already hard. This principle is proven by the presence of petrified wood on top of the Stella Mountain in Graubünden as reported by Scheuchzer (1709, p. 43)[6], by the occurrence of "natural walls" on top of the Rigi, and by the presence of boulders on high mountains mentioned by Swedenborg (§ 20). 3. Various inundations occurred with a long time span between them. Since the material on top of the Rigi consists of abraded stones, it follows that a long period of time must have occurred between the two floods during which the earth in its first state of liquidity changed into dry land with mountains, rock layers, and rivers. Sulzer added, that one finds rarely a stone in the plains which does not exist in larger masses in some high mountain (§ 22). 4. Mountains were not formed at the same time and in the same fashion. Indeed, large mountains existed before small ones as proven by their content. Their shape proves also that the latter were formed in a different manner than the former (§ 25). 5. The materials in orderly layers in mountains were deposited in sometimes agitated, sometimes calm waters. Indeed, had all the material been deposited in calm waters, the mountains would consist only of one layer (§ 26).

Sulzer proposed the following experiment to prove the fifth principle:

> Take a bucket of water. Throw in a few handfuls of very dry earth mixed with sand. When the earth is completely disaggregated, stir with a stick so that the earth is thoroughly mixed with the water. Let the earth settle until it has reached the bottom of the bucket. Stir again after having added some more sand. After several repetitions of this procedure, the water is removed from the top so that the earth can dry. After drying, there will be a mass of earth which consists of as many layers as the number of times the water was stirred and then left calm (§ 27).

Sulzer's sixth principle said that mountains have changed either entirely or partly from their first horizontal position by earthquakes or other causes (§ 28).

For his final theory, Sulzer added four "mathematical" (today physical) laws: 1. In the beginning, the earth did not rotate around its axis. 2. The earth before its movement around its axis was entirely spherical, soft, and covered by water. 3. The spherical shape of the earth changed because of the movement around the axis and the surface of the earth enlarged. 4. The center of gravity of the earth changes constantly (§ 31-38).

Sulzer explained first the origin of *large mountains* according to "mathematical" laws and said that a body has the smallest possible surface when it is entirely spherical. When the earth started to rotate around its axis, centrifugal forces flattened the poles and elevated areas at the equator. Therefore, the surface of the earth became enlarged so that some areas toward the poles were no longer

[6] Scheuchzer's observation is certainly a fable. However, there is a Piz Stella (3163 m), north of Chiavenna, in the valley of San Giacomo, Italy, which consists of pre-Triassic paragneisses of the lower Pennine "nappes".

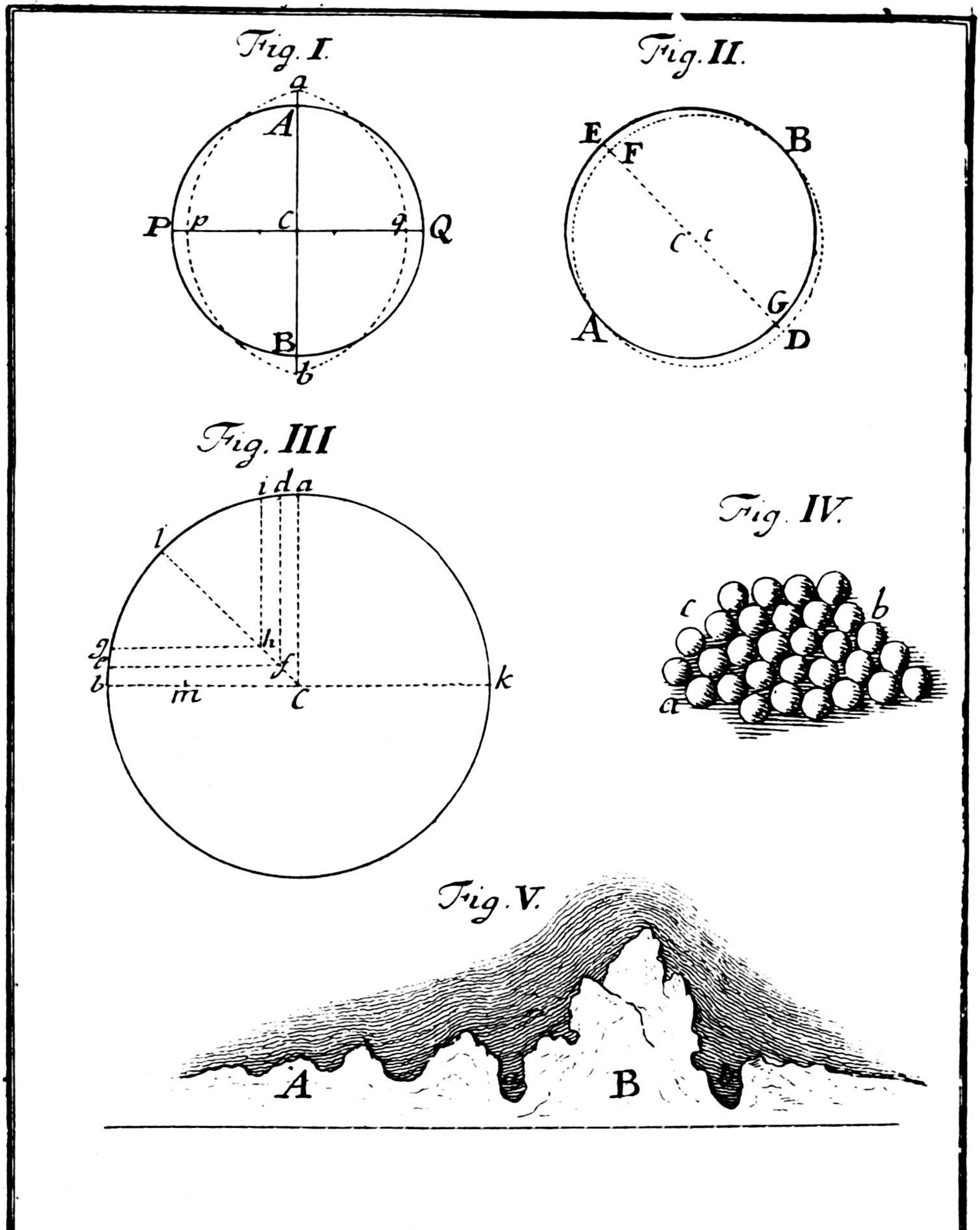

FIGURE 3.

Plate T 29a (Figures I to V) of *Sulzer Untersuchung von dem Ursprung der Berge*... (1746) in Scheuchzer *Natur-Geschichte des Schweizerlandes* (1746). Unique copy at Zentralbibliothek Zurich (Res 1362), vol. II, facing p. 373.

covered by water (§33). In Figure I (our Figure 3)[7], he showed what happened to the spherical shape of the earth when it started to move around its axis. Maupertuis (1742, pp. 71-72, 105-106), said Sulzer, had indeed proven that the poles are flattened and that equatorial countries are raised (§34). Sulzer added that the center of gravity changes when one part is removed at one place and added elsewhere; in fact, the center of gravity changes constantly. Causes might be due merely to transportation of earth by large rivers. For instance, the Yellow River in China is said to transport one third of the earth from one place to another (§35). Figure II (our Figure 3) shows that a new equilibrium is established when the center of gravity changes. At this point, some areas on the surface of the earth are inundated and others dry up (§36). Figure III (our Figure 3) explains what happened during the first rotation when various columns of earth sections, some from the equator toward the center of the earth, others, at right angle from the poles toward the center of the earth, lost their equilibrium (§39). The ones closer to the center of gravity, at the poles, pushed up the lighter ones at the equator and caused an elevation of the earth at the equator and flattening at the poles. However, because of unequal thickness and hardness of the earth's interior, other mountains elsewhere than at the equator might also have been elevated as shown in Figure IV (our Figure 3). This explains why mountains are scattered all over the earth (§41).

Sulzer then argued that "when mountains were elevated at the equator and when valleys were lowered in the polar region, mountains in horizontal layers, whose parts were not too well consolidated, often fell down in large masses from the newly emerged mountains" (§46). He explained with an experiment that earth- or rock-layers collapse when they are suddenly without support:

> Take some slightly wet ash, earth, or sand. Fill a trough made by four planks. Compress and push together ash, earth, or sand. Take away the four planks at once. A great part of the material will fall because, without support, it cannot form a compact mass. The remaining material will display more or less the shape of a large mountain with many peaks. One can, therefore, conclude that large mountains acquired their shape from such a removal of material (§29).

Sulzer saw, furthermore, an analogy between earth-cliffs and the shape of large mountains:

> A few hundred feet from the castle Weyden, on the river Thur, exists a steep bank called the "Dätweiler-Felsen". These rocks were named such, although they consist merely of earth, because their exterior shape is so similar to the shape of large mountains. The origin of these "Felsen" was as follows: the bank

[7] This plate does not exist in other bound copies of Sulzer's translation of Scheuchzer's travels that we have looked at. We found it only in a unique unbound copy at the Zentralbibliothek of Zurich (code Res 1362, volume II, plate T 29a, p. 373). This plate must have been originally omitted through a printing error and tipped in by hand on the external margin of page 373. Consequently, in most bound copies, the plate is missing having been cut off during binding.

> of the said river was at this place 30 to 40 feet high. Because the waters of the river removed the base of the high riverbank more and more, it became finally so steep that the earth could not remain in place any longer so that part of it fell into the river. The remaining earth took on the above-mentioned shape which resembles the one of high mountains (§ 30).

Sulzer understood that the external shape may differ from the internal structure when he mentioned:

> If all layers at the surface as well as in the interior of mountains are divergent from the horizontal position, then there must be another reason, namely the whole mountain itself must have departed from its upright position because of two reasons: earthquakes or collapse of the base of the mountain because of caves (§ 46).

Sulzer's explanation of the origin of *large mountains* is clear whereas that of *small mountains* seems to suffer from his inability to find a valid alternative to Scheuchzer's Deluge. It seems as if he had written the essay merely to refute Scheuchzer's opinion that large *and* small mountains were formed during the Deluge. Once he had given a new theory for the formation of large mountains, he seemed unable to explain the origin of small ones. He stated, therefore, that one of the inundations which formed the small mountains might in fact be the Deluge mentioned by Moses. However, he admitted that he did not know whether the present surface of the earth could be explained by this flood alone and said that further studies were required (§ 51). Nevertheless, he conceded that the center of gravity must have changed during the Deluge so that the whole "Haemisphaerium" was flooded. When the center of gravity changed back to its former place (if not entirely, at least partially), the other part of the earth became flooded. In both cases, waters transported tremendous amounts of earthy material (§ 53). The waters of the flood were calm in deep valleys whereas they were highly agitated close to mountains as shown by Figure V (our Figure 3).

Which are the large and small mountains Sulzer had in mind? He referred twice to large mountains with highly visible rock- layers along the Uri Lake (§ 4-5) which are undoubtedly those sketched by Scheuchzer's brother Johann (mentioned in footnote No. 2 and illustrated in our Figure 2). These are the High Calcareous Alps which originated in various basins of the Tethys Sea where sediments were compressed, uplifted, and thrusted over great distances to form the spectacular overthrusts or "nappes". Their massive limestone layers (Middle Cretaceous) show fossils only upon close examination and hence appeared homogeneous to Sulzer who had seen them from the boat (Sulzer, 1746*a*, p. 46).

Sulzer's small mountains are accumulations of either Molasse or glacial material which occur essentially in the same areas in Switzerland, namely in the plains between the Jura Mountains and the Alps, and also in the first valley of the Jura as well as in Alpine valleys. Nagelfluh is present in many medium-sized mountains such as the

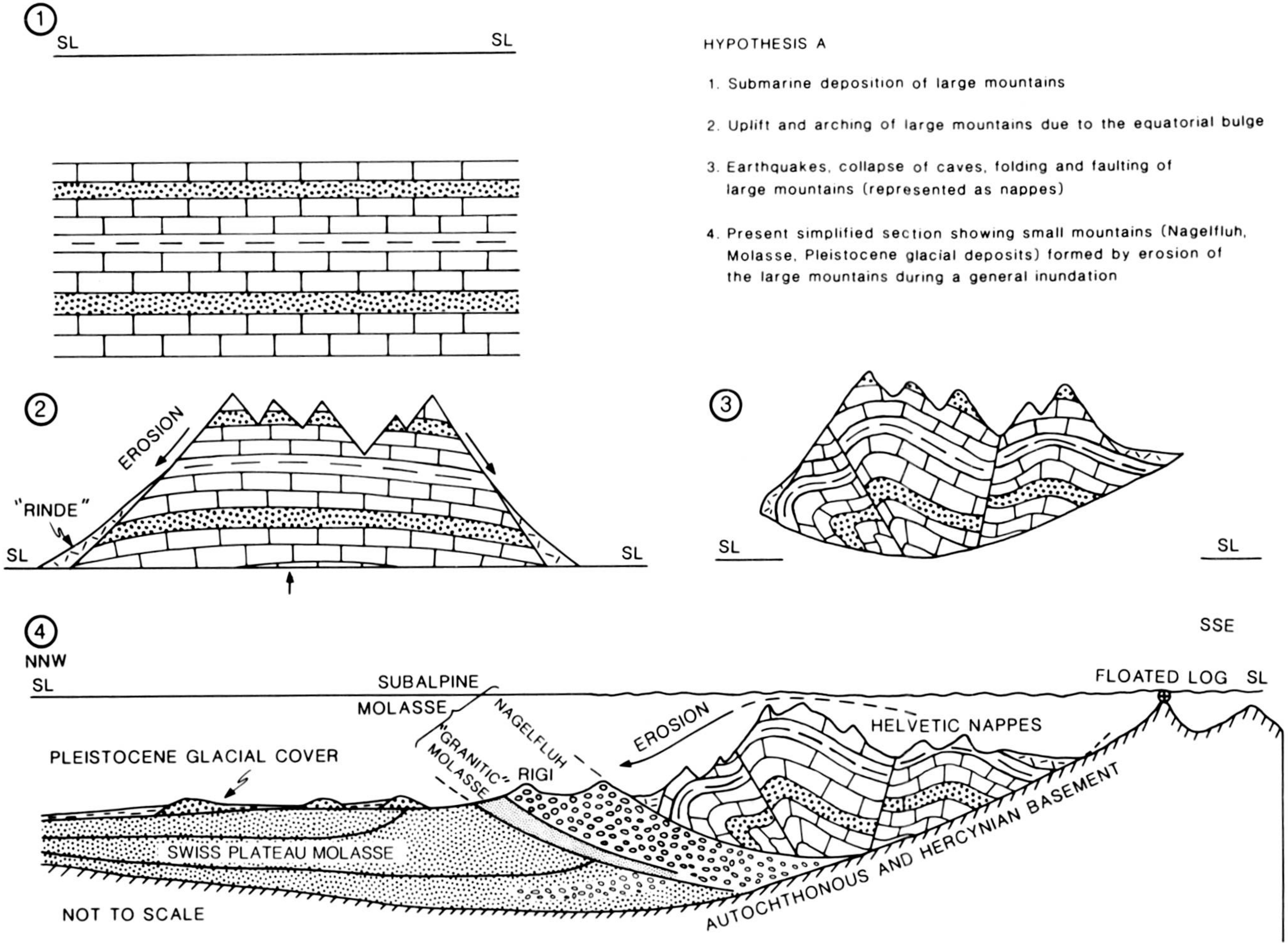

FIGURE 4.

Interpretation of Sulzer theory of the earth (1746), Hypothesis A.

Rigi, the Napf, the Speer, the Hörnli (Baumberger, 1934, Plate V, pp. 57-75; Trümpy, 1980, pp. 24-30). During the Alpine orogeny (Oligocene to Miocene), fluvial-deltaic and marine detrital formations accumulated in the Molasse Basin north of the present Alps and at the southern foot toward Italy. Molasse contains thus either terrestrial or marine fossil plants and animals.

Molasse formations can also be overthrust as in the case of the Rigi. Sulzer's greatest dilemma was indeed the presence on top of the Rigi of cemented stones overlying what he believed to be older granite (Geissberger-Stein) which is in fact a massive feldspar-rich sandstone called "granitic Molasse". The only explanation he could think of was transportation by waters of these cemented stones and deposition on top of the older already hardened rock. In fact, in the Rigi area, the Subalpine Molasse which consists of Stampian Nagelfluh (Sulzer's "natural walls") overlying the "granitic Molasse" is thrusted over the Aquitanian freshwater Molasse of the Swiss Plateau (Figure 4,4, see Buxtorf, 1957, pp. 24-25).

Moraines and other glacial deposits of the Pleistocene ice-ages were also small mountains according to Sulzer. No wonder, certain glacial deposits look very similar to Molasse because they can also consist of variously cemented outwash gravel, hence Sulzer's confusion of small mountains in the plains with those on top of the Rigi.

Sulzer's theory of 1746, called here Hypothesis A (Figure 4) can be represented in four stages:

1. Homogeneous (gleichartige Felsen § 3) stratified sediments were deposited in the sea by alternating calm and agitated waters during many centuries. According to his experiment, the first layer had to be hard before the next could be deposited without mixing of the material (§ 27).

2. Uplifting and arching of the first layered mountains occurred due to the equatorial bulge (§ 39). Some unconsolidated material slid down and subsequently became cemented at the foot of the mountain (Sulzer called this feature "Rinde", which is probably a talus or scree, § 28, 44, 46). Bare peaks were formed which resemble earth-cliffs (Dätweiler-Felsen, § 30).

3. Earthquakes and collapse of caves caused folding and faulting of the first indurated layers (§ 28, 46). This final deformation of stratified mountains involved both the surface and the inside of mountains (§ 46).

4. A second flooding covered the highest mountains as proven by petrified wood (floated log) on top of a high mountain according to Scheuchzer, the presence of "natural walls" on top of the Rigi, and Swedenborg's observation of boulders on high mountains (§ 20). Highly agitated waters are responsible for deposition of "natural walls" on the Rigi (§ 21) whereas calm waters laid down earths, coal, shales, fossils in restricted valleys (§ 23). The second flood also deposited piles of cemented

or non-cemented pebbles in the plains (§22) and washed away sand from between sedimentary layers of the first mountains leaving fissures between layers (§5).[8]

SULZER'S IDEAS COMPARED WITH THOSE OF OTHER NATURALISTS OF HIS TIME

Sulzer's work strikes as a fresh approach to the investigation of sedimentary processes involved in the deposition of layered earths and rocks and their subsequent uplift, folding, and fracturing. Before him, Nicolaus Steno had suggested that layers of sedimentary rocks were once deposited horizontally by water: "The strata of the earth, as regards the place and manner of production, agree with those strata which turbid water deposits" (1669, reprint 1968, p. 219). He proposed, furthermore, that these originally horizontal layers were later uplifted, folded, and broken by violent thrushing up of strata due to subterraneous fires or gases or by collapse because of withdrawal of the underlying substance or foundation (pp. 230-231). Before 1746, few naturalists tried to explain such folded and fractured strata when found in their own country.

Among the few was Emanuel Swedenborg whom Sulzer mentioned several times in his theory on the origin of mountains. Swedenborg believed that layered mountains consisting of clays, sand, shales, calcareous earths, huge accumulations of stones mixed with sand running north-south, as well as the presence of large boulders strewn in the plains and on top of mountains, were the effects of an ancient universal ocean (1722, translation 1847, p. 7).[9] He noticed that some mountains display variously inclined positions of layers. In a laboratory experiment, he put some heavy stone at the bottom of a glass and added sand and clay which acquired a draping structure over the stone. According to Swedenborg, inclined layers, therefore, indicate the effects of irregularities of their substratum (pp. 15-18). In regard to the emergence of mountains, he proposed that due to the rotation of the earth, the waters left the polar regions and flooded the equator. He specified that "horizontal pressure of our world is liable to change which necessarily follows if the seas are depressed towards the poles, and raised, as reported towards the equator" (p. 152).

Sulzer was certainly influenced by Swedenborg's alternative to the diluvial explanation of small mountains. He accepted his observation of boulders on top of

[8] Limestone cliffs which stand out sharply in the landscape on both shores of Uri Lake are the result of differential erosion of shaly layers between highly deformed and faulted limestones of the High Calcareous Alps "nappes".

[9] Sulzer referred to Swedenborg's small paper "De generatione solidum in Oceano primaevo &c de Oceani illius altitudine" in the preface to the Prodromus *Principiorum rerum naturalium* (1721). A year later, Swedenborg published *Miscellanea observata circa res naturales* (1722), where the main ideas are repeated, which was translated into English in 1847. This is the source used here.

mountains as having been transported by a powerful ancient ocean but doubted that the pyramid shape of large mountains could have been formed under water since strong ocean currents would have rounded them instead (§ 16).

In 1729, Louis Bourguet noticed that many rock layers have several inclinations, namely horizontal, perpendicular, variously inclined, folded in a concave manner, folded in a convex manner, circular, wavy, folded in zigzags. He stated that the thickness of these folded layers was the same throughout (1729, p. 202). He also referred to the equatorial bulge stating that a famous geometer, Mr. Hermann, had explained to him in a letter:

> It does not seem unreasonable to me that centrifugal forces are responsible for the formation of mountains since one can observe that the highest are indeed at the equator, that is in the place where the centrifugal force is strongest. Winds may also have contributed a great deal since in the northern countries we also find high mountains where the centrifugal force is very small. Many observations are needed on the altitude of mountains, on the position of their strata, and their inclination to the horizon, as well as on the specific weight of the various materials. A comparison of all these observations, I am sure, will prove the laws of mechanics although this study requires long discussions (1729, pp. 189-190).

Bourguet could not resist the challenge and produced a sketch of a theory of the earth where he explained the formation of mountains not only at the equator, but also in a south-north direction by the interplay of the forces involved in the earth's rotation around its axis and around the sun, and the attraction of the moon which produced ripples of mountains running north-south and east-west (1729, pp. 211-215, for a closer analysis see M. Carozzi, 1986). Bourguet thus explained mountain-chains which circled the globe east-west and north-south as mentioned earlier by Athanasius Kircher (1664-1666, Tome I, Book II, Chap. IX, p. 69).

At the beginning of his theory, Sulzer immediately refuted the idea of such rigid mountain-chains. He said that, on the contrary, mountains exist everywhere in a random fashion, that no certain rule exists about their altitude and number in a given place, and that mountains are as high in the polar region as at the equator (§ 1). He, therefore, did not accept the view proposed by Kircher, Bourguet, and others but believed that the center of gravity changes constantly due merely to transportation of earths and waters from one place to another so that the equatorial bulge, or simply the equator, changes constantly too.

LEHMANN'S THEORY ON THE ORIGIN OF FLÖTZ-GEBÜRGE COMPARISON AND CONTRAST WITH SULZER'S THEORY

Lehmann was appointed "Bergrat" to study mining procedures in the Prussian provinces and traveled extensively. Four years after Sulzer, he became member of the Royal Prussian Academy of Sciences in 1754 (*Verzeichniss der Abhandlungen...*, 1871, pp. 134, 192). Sulzer and Lehmann were of the same age and Lehmann must have read Sulzer's theory on the origin of mountains. In 1756 he published his influential *Versuch einer Geschichte von Flötz-Gebürge...* which is still famous today because of the stratigraphic section of Flötz-Gebürge at the southern edge of the Harz in North Thüringen.[10]

In *Versuch einer Geschichte von Flötz-Gebürge...* Lehmann explained in particular the history of stratified mountains but he included also a theory of the earth and a short summary of that theory at the end as follows:

> ... Our earth-crust was before the separation [of solids and liquids] a disaggregated earth suspended in a large mass of water. This earth settled during Creation and the waters collected in seas, lakes, or in abysses, and in the center of the earth. The earth crust [Erdboden] became dry and consisted henceforth of plains and mountains which are still existing today. By their altitude, their inner structure, and other aspects, they differ from those called Flötz-Gebürge. This earth-crust suffered various changes which did, however, not amount to a major change of the original earth-crust. After some time, a general inundation of this large body occurred. We can merely speculate about the origin of this event. It suffices to say that it was a general flood which swept over the highest peaks of mountains on which traces of various kinds were left. These waters disaggregated many clayey and calcareous earths which were suspended in the waters for some time before settling, thus forming completely new layers on the flat land. While the waters left the high mountains, they carried away some more of the same earths as well as various animals, snails, fish, and shells which settled during a diminution of the waters on top of the first layers. Finally, the waters disappeared completely and the earth-crust, in particular at the foot of high mountains, received many layers which had not existed before and which are called Flötze. That they originate from a flood is proven by buried, petrified, or imprinted plants and animals. After a while, parts of the earth underwent further changes by partial inundations, landslides, earthquakes, volcanoes, etc. These changes were, nevertheless, not as important as those during the general flood. The layers formed during that great flood slowly became impregnated by the metallic and meteoric waters from the primordial mountains. The Flötz-Gebürge became thus mineralized and they now contain those minerals or metals which were plentiful in the adjacent primordial mountains (pp. 238-240).

In this theory we recognize the ideas that during a general inundation, waters swept over the highest mountains, that they disaggregated clayey and calcareous earths which were suspended for a while before settling and then formed new layers

[10] Flötz-Gebürge means stratified mountains whereas "Flötze" are layers of sedimentary rocks. Lehmann's sketch of the stratigraphic section on p. 162 is explained by Freyberg (1955) and Haarmann (1942).

on the flat land, that these waters carried earths as well as various fossils. These ideas are clearly spelled out in Sulzer's theory on the second flooding when small mountains were being formed (§ 53-54). Lehmann mentioned also that near high mountains, the waters were most agitated, "at first they merely pushed against them. But when they gradually reached the highest peaks and swept over them, they acquired a stronger push and greater strength" (p. 84). Is this not exactly Sulzer's explanation for his Figure V? (our Figure 3).

It is obvious that Lehmann agreed with all but one of Sulzer's principles, namely: 1. The earth was once in a liquid or at least in a very soft state. 2. Water formerly covered the highest mountains when these were already hard. 4. Mountains were not formed at the same time nor in the same fashion. 5. The material in orderly layers in mountains was deposited in sometimes agitated and sometimes calm waters. 6. *Some mountains have changed either entirely or partly from their first position* by earthquakes or other causes. Indeed, Lehmann disagreed only with Sulzer's third principle which said that various inundations had occurred with a large time span in between them.

Lehmann preferred to adher to the short time allotted by Ussher's time-table (1650-1654, p. 1). Indeed, Lehmann agreed with Elie Bertrand's classification of mountains (1752, pp. 98-131) according to which some mountains were formed during Creation, others during a general inundation or the Deluge, and others are still being formed today according to local events (Lehmann, pp. 54, 95-96). Lehmann seemed hesitant between the acceptance of the earlier belief of a Deluge held by his predecessors in Germany, William Ernst Tentzel, David Sigismund Büttner, and Friedrich Christian Lesser (Wiefel, 1974, pp. 14-15) and the more revolutionary idea of the diminution of the sea proposed by Maillet (1748) or Sulzer's theory on changes of the center of gravity. He preferred to remain cautiously in the middle and said that Flötz-Gebürge were deposited during a general inundation of short duration, perhaps caused by the Whistonian comet (p. 82). He accepted only visible changes along the sea shores saying: "Observations strengthen our belief that the sea retreated in various places and left dry land whereas it carried away solid land elsewhere and took its place; de Maillet under the name of Telliamed has proven this with curious remarks and the famous Professor Sultzer, in his essay on the origin of mountains, has shown this even more precisely" (p. 41). Underplaying Sulzer's theory, Lehmann said: "The remarks made by Professor Sultzer on the origin of mountains in regard to the retreat of the sea and other causes, described with much care, convinces us of daily changes of the earth-crust" (p. 88). It is clear that Lehmann had read Sulzer's theory, that he respected him as a famous professor, but that he did not believe in any global changes as proposed by Sulzer.

Whatever religious constraints existed for Lehmann, he was also too practical a man to adopt Sulzer's abstract ideas on the origin of the first mountains. In his essay, he wanted above all to give, mostly for economical reasons, a clear picture of the content of the Flötze. Why do we need to know better the interior of the earth? he asked. First, for the benefit of science in general. Second, to provide a geographical map of mineral deposits for the use of the "Grosse Herr" as well as the "Particuliers". Third, to put this knowledge to use. Fourth, to find metals in places where we did not look for them before. Fifth, how many factories would not profit by this information? Sixth, how many people would not make a living in these factories? Seventh, how many unnecessary projects would not be eliminated so that many promoters could keep their money instead of losing it to swindlers? (Preface a5) Lehmann's practical approach to the earth sciences won him d'Holbach's esteem and translation into the French language (Lehmann, 1759).

Nevertheless, it has not been recognized that Lehmann accepted most of Sulzer's principles on the origin of layered mountains (Sulzer's large and small mountains) with the exception of some very important concepts such as a long time span which was necessary for the formation of several layers and not only one general flood. Indeed, Sulzer emphasized that large mountains display up to forty layers of sandstone, limestone, shales and that some small mountains consist of distinct layers of sand, gravel, and earths indicating successive inundations which could not have been deposited during one single flood. Lehmann, furthermore, neglected to explain folding, tilting, or other anomalies of Flötze and drew merely an ideal section saying that he wanted to show only regular layers (p. 155).

Lehmann and Sulzer differ particularly in their interpretation of the "older" and "younger" mountain. Indeed, Lehmann accepted the belief that Gang-Gebürge date from Creation when liquids and solids separated whereas according to Sulzer, large mountains were deposited in many layers during a long period of time in the universal ocean from which they emerged when the earth started to rotate. The reason for their different interpretation lies in regional geology. Lehmann's Flötz-Gebürge abutt against an older mountain, the Harz, with immense vertically plunging masses, rich in metallic ore veins, whereas Sulzer was looking at layered mountains, the "nappes" of the High Calcareous Alps, which do not abutt against an older mountain, hence his belief that they were the oldest.

D'HOLBACH'S REFERENCE TO SULZER IN HIS ARTICLE "MONTAGNES"

Sulzer's ideas on the origin of mountains were referred to in detail, but misinterpreted by d'Holbach. He cited Sulzer's theory on the equatorial bulge in his article "Montagnes" in the *Encyclopédie* of Diderot (1765, vol. 10, pp. 672-676) saying: "M. Schulze[11] published in 1746 a German edition of the Natural History of

[11] D'Holbach mistook Sulzer for the astronomer Johann Carl Schulze, both members of the Royal Academy of Sciences at Berlin. See *Verzeichniss der Abhandlungen...* 1871, p. 185 for Schulze and pp. 192-194 for Sulzer.

Switzerland by the famous Scheuchzer. He added a dissertation on the origin of mountains of which we give here an abstract''. D'Holbach then cited Sulzer's theory on the origin of mountains due to the equatorial bulge based on observations by Maupertuis adding that according to Sulzer:

> The highest mountains should be located close to the equator which is confirmed by the most recent and exact observations. But according to his system, the direction of these mountains should be the same as that of the equator which is not so. Indeed, we see for instance that the Cordilleras cut the equator at right angle. Furthermore, the mountains of Norway and of Russia, as well as the Alps and the Pyrenees — which are certainly mountains of the first order — are nevertheless located very far from the equator (1765, vol. 10, p. 675).

As mentioned above, Sulzer's theory on the origin of ''large mountains'' was based on Maupertuis' calculations of the flattening of the poles and the equatorial bulge. However, Sulzer had proposed a random location of mountains all over the globe and not only at the equator as d'Holbach understood. D'Holbach was probably influenced by his prejudice in favor of north-south and east-west trending mountain chains which he described in the article ''Montagnes'' as forming ''la charpente de notre globe'' (the frame of our globe):

> Primitive mountains differ from others by being in vast chains which are held together for many leagues. P. Kircher and many others have noticed that these mountains form circles around the earth which have a north-south or east-west trend... Underneath the sea, these chains appear in islands... Some mountains are isolated but they must, nevertheless, be connected to other mountains on land. Primitive mountains can, therefore, be regarded as the base or the frame of our globe (1756, vol. 10, p. 673).

D'Holbach was obviously not following Sulzer's train of thought because he chose to believe in a stable encircled earth. His philosophy, expressed in *Système de la nature* says: ''Everything is connected: a great chain exists between cause and effect. Everything is necessary'' (1745, reprint 1966, p. 60). Indeed, d'Holbach chose to believe in Philippe Buache's ideas of continuous mountain-chains on land and under the sea. Buache, first geographer of the King of France and member of the Academy of Sciences at Paris, was extremely famous because his system pleased his contemporaries. Louis XV asked him to teach geography to the future Louis XVI, Louis XVIII, and Charles X (Broc, 1969, pp. 56, 61). Buache presented the world as a network of mountain-chains which continue underneath the ocean in the form of islands and shoals. The system was, however, merely based on measurements in the Channel presented to the French Academy in 1737 (1752, pp. 399-416, see in particular p. 412).

D'Holbach, furthermore, misinterpreted Sulzer's distinction between ''large'' and ''small'' mountains when he said:

> In regard to layered mountains, M. Schulze believes that various parts of the

earth have suffered repeatedly distinct inundations which have deposited different beds. These deposits occurred either in calm water or in highly agitated ones. These inundations swept at times over the summit of the oldest mountains. This is why some mountains consist of layers of earth and accumulations of stones and debris. He tells us that he found on the summit of the Rigi Mountain in Switzerland an accumulation of rounded pebbles held together by a cement of silt and sand. He claims that there were as many inundations as there are different layers, that these inundations occurred at great intervals, and that earthquakes and collapse have disrupted and destroyed some mountains. This shows that they could not have been formed at the same time nor in the same fashion (1765, vol. 10, pp. 675-676).

In the text mentioned above, d'Holbach seemed to understand that Sulzer's layered mountains ("montagnes par couches") were merely mountains of recent origin whereas Sulzer distinguished, in fact, large mountains consisting of rock-layers, which exist since the earth started to rotate, from small stratified mountains consisting of earths and sand which were formed during later inundations. This misunderstanding probably resulted from d'Holbach's personal belief that primitive mountains exist since the beginning of the world and that recent mountains were formed later either by volcanic eruptions or by marine inundations.

Indeed, in his article "Montagnes", d'Holbach said that primitive mountains are of high elevation and consist of peaks and cliffs, separated by deep valleys. They occur in vast chains all over the globe and differ from recent mountains by their immense and uniform masses extending vertically to great depths, by the presence of "hornstein" and pure marbles and, in particular, of metallic ore veins ("filons"). Such primitive mountains are in Europe, the Pyrenees, the Alps, the Apennines, the Harz, and so forth. Recent mountains were formed either by volcanic eruptions or by inundations. Those formed by inundations have rounded or flat external shapes; they are stratified and often covered by earths, fragments of stones, abraded pebbles which seem to have been transported by running water such as streams. Their great lithologic variety (slates, clays, chalks, limestones, sandstones, coal, salt, gypsum), the huge amount of fossils they contain, and their horizontal or weakly inclined layers indicate a marine deposition. Subsequent earthquakes, revolutions, or collapses deformed and dislocated these layers (1765, vol. 10, pp. 672-675).

It should be recalled that at the time of Sulzer's theory on the origin of large and small mountains, the concept of "older" and "younger" mountains was extremely vague. It was normal to consider a mountain to be old or to exist since the beginning of the earth if it consisted of high peaks or showed no older substratum as believed by Elie Bertrand in the Jura Mountains (see M. Carozzi and A. V. Carozzi, 1984, p. 273) or if it seemed to belong to a chain of mountains which surrounds the globe as believed by Bourguet (1729, pp. 211-215) and many others. It is, therefore, not surprising that Sulzer believed in 1746 that the High Calcareous Alps with their many peaks and cliffs should belong to the category of "large mountains". D'Holbach, on the other hand, had just translated Lehmann's book on Flötz-Gebürge surrounding the older "Gang-Gebürge", where the idea of older versus younger mountain was clearly expressed. Lehmann was the lucky naturalist who actually described what we now know to be the older granitic Harz surrounded by younger mountains. D'Holbach adopted Lehmann's concept of primitive mountains which differ from younger ones by their appearance, their lithology, and the presence of metallic ore veins and he thus misinterpreted Sulzer's distinction of "large" and "small" mountains.

SULZER'S EXPLANATION OF THE DEBRIS ON THE SURFACE OF THE EARTH BY CATASTROPHIC DISCHARGE OF HANGING LAKES (1762)

Sulzer certainly read Lehmann's book and encountered the idea that layered mountains were formed by a general inundation during a short period of time. Moreover, he found no explanation whatsoever on the origin of his small mountains or debris. While in Magdeburg as private tutor and later in Berlin as professor at the newly founded "Ritterakademie" (an academy for aristocrats) by King Frederick II, Sulzer visited some of the same mountains which Lehmann had described in his work (for instance the Brocken). In the plains north of the Harz, he found many accumulations of debris similar to those he had described as small mountains in Switzerland. These observations, Lehmann's book, and a trip to Switzerland in 1762, where he passed through Bern, Basel, Zurich (Sulzer, 1809, pp. 34-35), prompted him, after twenty years of silence on the subject of mountains, to write another essay in which he treated only the origin of small mountains (1762).

In the first paragraph, Sulzer explained the scope of the paper:

> The present surface of the earth shows signs of several extraordinary revolutions which must be responsible for its present state. The entire earth, with the exception of a few places, is covered with a crust of debris of variable thickness. In certain places, this crust consists of regular layers of earth, sand, gravel, stones which rest horizontally one on top of the other but very rarely according to the order of specific gravity of each layer. In other places, this crust consists of an accumulation of heterogeneous material which seems to have been deposited randomly. One finds various kinds of earths, sands, pebbles mixed together and in the middle of this heterogeneous material, one finds sometimes remains of plants and animals. Finally, great amounts of sand cover the surface of the earth in many places and down to great depths. The least philosophical mind perceives

> that this crust is not the primitive material which covered the earth originally. The sands which cover entire regions are merely broken rocks, stones, and crystals, and the stones which cover the land at various places, are merely detached pieces of certain rocks which form the primordial substance of mountains (p. 90).

Sulzer's approach has clearly changed since his last paper written in 1746 where he had given an interpretation of large and small mountains. Now he simply referred to small mountains and asked: "What revolution caused the earth to be covered by this heterogeneous crust"? He stated that naturalists have been unable to answer this question and that the problem has bothered him for many years (p. 91).

Sulzer referred here to a landscape north of the Harz Mountains where the largest ice-sheet of the Elster glaciation as well as of the Saale (Riss) glaciation covered the area from the North Sea to the foot of the Harz (Figure 5). Glacial and interglacial deposits fill, for instance, basins and troughs up to 300 to 324 m deep whereas ground moraines cover flat areas. Many lakes were formed between frontal moraines where clays deposited in annual layers. Directly north of the Harz were deposited outwash gravels with bones of rhinoceros and elephants (Lotze, 1971, pp. 245-253).

A trip to the Hercynian mountains (the Harz including the Brocken as its highest peak), said Sulzer, had given him ideas which might shed some light on certain problems. In order to understand these ideas, he referred the reader to a sketch (Figure 6) which "represents a random part of a section of the earth". "A" is the sea level, "M" is the highest mountain in that area, the Brocken, also called Blocksberg. He imagined that the mountains in between the two points represent that portion of the Hercynian mountains which is between the village of Ilsenburg and the top of the Brocken (p. 91). During his descent from the Brocken he arrived at the last gorge which resembles a door and he thought:

> If this passage were closed by a wall, the small river which crosses the valley F and emerges at D, when finding no exit would increase in size and transform the valley EFG into a deep lake. If the waters of this lake could find some fissure at the base of the mountain DEF through which they could escape, the high pressure of the waters on the bottom of the lake, which is several hundred feet deep, would force them to escape with great violence to which nothing could resist. Little by little, the waters would enlarge the path and would transport all earths, sands, and stones which they would find on their path. They would transport such great quantities with such violence that after the discharge of these waters, the plain would be covered with much debris between D and C. The opening at the foot of the mountain (D) would have first increased in size; when part of the mountain would have lost its base, it would collapse and the debris of this collapse would also be scattered over the plain. These observations made me grasp the reason why the plains between D and C are covered by debris which

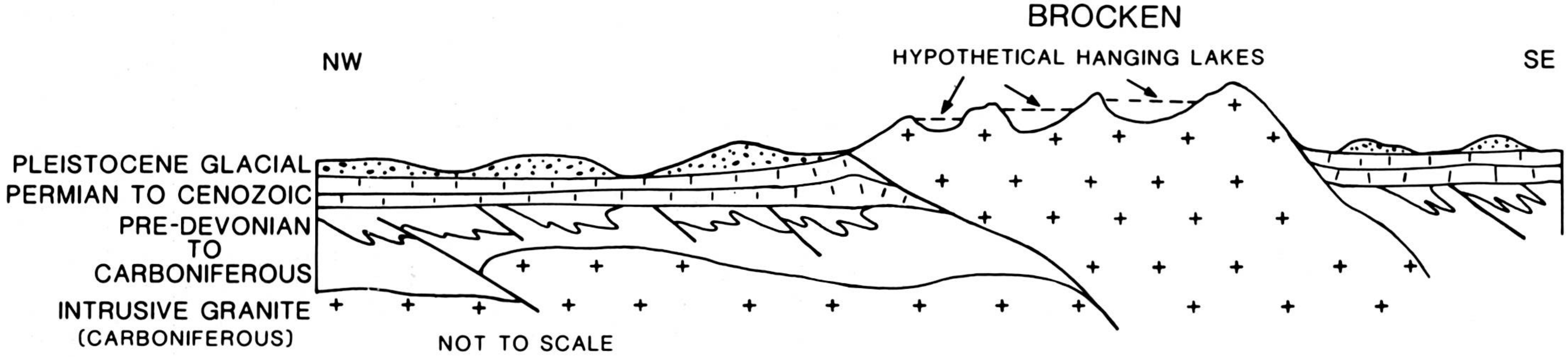

FIGURE 5.

Simplified geologic cross-section of Brocken with hypothetical hanging lakes of Sulzer. Modified from "Schnitte durch Nordwestdeutschland" by W. Schott and H. Lögters in *Geologische Übersichtskarte von Nordwestdeutchland* 1: 300.000. Amt für Bodenforschung, Leitung A. Bentz, 1951.

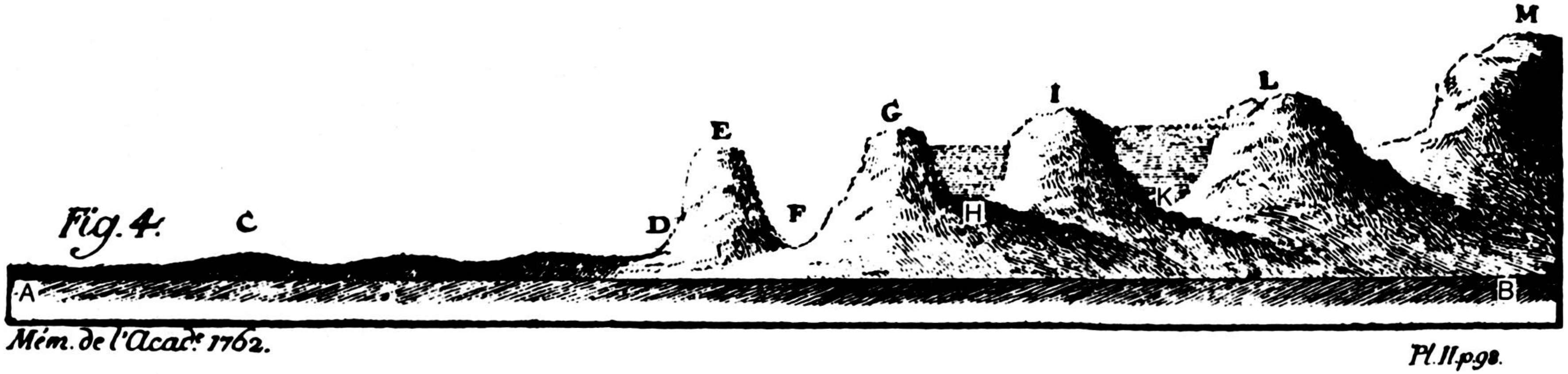

FIGURE 6.

Cross-section between Ilsenburg and Brocken by Sulzer showing hypothetical lakes. "Conjecture Physique...": *Histoire de l'Académie royale des Sciences et Belles-Lettres,* Berlin, 1762, published 1769 (Pl. II, p. 98).

originate from fairly distant mountains and how this debris can be accumulated to great heights. I understood finally that cases exist when accumulations can

> be so great that they fill the bottom of the ocean close to the shores and force the waters to retreat (p. 92).

Sulzer's new concept proposed that waters escaped from hanging lakes located in large mountains (Figure 5) whereas in his earlier theory, he had stated that a change of the center of gravity had caused powerful floods which formed small mountains from the erosion of large ones. Based on this ingenious concept, Sulzer was now ready to propose a new theory:

> First, I suppose that in its primordial state, the surface of the earth was covered with water with the exception of these areas where great mountain-chains occur today. In the past, these mountains formed islands in the middle of the ocean. In our particular sketch [Figure 6], the area between A and D was covered with water. It does not follow that the waters of the ocean ever covered the plain ACD which we see today, but that all the accumulations of debris which exist between A and B and ACD were not there in the beginning. This theory not only proposes very probable facts, but also becomes almost true since in all countries one can dig far below sea-level without ever finding any earth or other material which could be considered primitive. It is a fact that earths which form the bottom of our present flat countries are mostly debris, therefore they were originally not there. This explains how the waters of the ocean could cover the entire surface of the earth with the exception of high mountains. If today one could remove all the heterogeneous earths from the places where they are deposited at present and put them back on top of the mountains, the quantity of water at the surface of the earth would be sufficient to cover all the plains (p. 93).

The difficult part of the new theory was to explain the presence and role of hanging lakes:

> In such a primitive state, the valleys which now exist in mountains were not opened as yet. All mountains showed at their outer limit inaccessible promontories; interior valleys were all filled with water and formed thus many lakes without any possible outlet for waters. The letters GHI and IKL show such lakes [Figure 6]. At that time, no rivers existed on the earth since the mountains were not opened to give access to the waters of lakes. All valleys received water from springs. I imagine that in several places, these lakes formed cascades along some promontories so that even in that state when no rivers flowed, a continuous circulation of the waters to the ocean, and from the ocean to the springs occurred by means of these cascades and by evaporation (pp. 93-94).

Sulzer stated that these lakes were very deep, at least several thousand feet, since some present valleys between high mountains have such depths. These lakes must have produced tremendous pressures on the bottom and on the sides closest to the bottom (p. 94). Since high mountains are exposed to heat and cold and to the action of humidity and since they are generally fissured in all directions, their surface became eroded and produced two effects. 1. The bottom of the lakes were filled with stones which fell from large mountains. 2. They were filled also by sediments of sand, earth, and clays produced by the disaggregation of rocks.

Looking back to the earth in this early state, Sulzer imagined some twenty islands in a universal ocean:

> In Europe, the Pyrenees, the Alps, the Bohemian mountains, the Hercynian Mountains and those of Thrace. It is not surprising to find today marine shells and fish in areas where the ocean once sojourned. On each of these islands, a great number of lakes of considerable depths existed with their bottoms filled with earths, sands, stones of every size. At that stage, very natural and common causes were able to produce successive changes which gave the earth its present surface. If an earthquake, for instance, broke a promontory which formed the exterior edge of a lake, waters would then rush out with violence in order to transport all the materials deposited at their bottom and remove, furthermore, other material found on their path. All this material would be carried to the sea and deposited there to form new islands. These new islands would consist merely of debris. Following this first escape of waters, others would occur which would be followed by others yet until all the lakes of one of our large island would be empty. These discharges happened at various times in the past and it is easy to understand how that part of the ancient ocean which occupied the space between two islands, for instance the Pyrenees and the Alps, was filled to the brim by debris and became habitable land (p. 95).

With his new theory Sulzer was now able to explain some poorly understood facts. In his order of priority, he first challenged the theory of the Deluge.

> Almost every civilization of the earth has mentioned inundations or floods which occurred in the past... Those who pretend that the Noachian Deluge was universal, believe that they could find proofs of this hypothesis in the traditions of other civilizations. But since the universality of any deluge is absolutely impossible to prove, it is necessary to find another explanation for the many inundations. Our hypothesis can provide such an explanation. Indeed, these inundations were merely particular escapes of water from great lakes... The discharges of debris produced a double increase of dry land. On the one hand, the bottoms of lakes became dry, and on the other hand, debris transported to some areas of the shallow ocean also formed dry land...
>
> It is easy to understand how a small civilization located between the sea and a great promontory was capable to believe that their flood had been universal. It is natural that Noah and Deucalion believed that they were the only men who had escaped from these terrible catastrophes (p. 96).

Sulzer then referred to his essay on the origin of mountains published about twenty years ago [1746*b*] in which he had mentioned certain features in the Alps which until now have not been explained by any theory.

> That a mountain of three thousand feet above sea level [the Rigi] was covered by an inundation and thus by a great amount of earths and pebbles mixed together is now easy to understand if one knows that at a short distance from this mountain existed valleys with floors two thousand feet higher than the said mountain. The discharge from these valleys may well have caused the said effect (p. 97).

This is Sulzer's most important change of theory. In 1746, he had attributed the presence of pebbles on the Rigi to a flooding of large mountains but seemed to have doubts about the origin of these floods. He also explained the presence of fossils at the foot of large mountains or in places of low altitude by the fact that an ancient ocean had been lapping against the island in the past whereas the great violence of waters under pressure had been capable of accumulating masses of earths and pebbles, including fossils, at higher elevations (p. 97).

Sulzer thought furthermore that he could explain now the existence of great lakes at the foot of the Alps:

> The lakes of Geneva, Constance, Zurich, Lucerne, Thun, as well as the Lago Maggiore, are evidently located at the gorges of mountains. Whoever has seen them might easily agree that these lakes were probably excavated by the violent waters emerging with tremendous strength from the neighboring valleys before these valleys were completely opened (p. 97).

As a last conclusion of his new theory, Sulzer then added that large layered mountains which were formed by deposits of several inundations were originally horizontal, but that a later collapse caused by catastrophic discharge of hanging lakes altered their position (p. 98). He gave no example of such inclined layered in the Brocken because it is a granitic mountain. This last conclusion appears, therefore, extremely vague and out of context in this essay. We understood what he meant only after the reading of his last paper in 1780 mentioned below.

Finally, he ended his essay stressing the importance of geological time:

> It is clear that all the events mentioned above must have occurred successively during several centuries. History has merely preserved the last great "érup-tion"... There is no reason to believe that the primitive state of the earth as mentioned above lasted only a short period of time and that all the changes which gave the earth its present form, occurred during short spans of time. Instead these changes must have lasted many centuries (p. 98).

In order that his second theory on catastrophic discharge of hanging lakes be complete, Sulzer needed accurate observations of folded layers in large mountains as well as some example of hanging lakes, either still filled with water or presenting deep valleys from which the waters had escaped. Almost twenty years later, he was able to observe these features in the Alpes Maritimes and the Swiss Alps.

SULZER'S LAST FLING TO NICE AND THE ALPES-MARITIMES

When his health started to fail, Sulzer traveled South, visiting on his way Goethe, Haller, Horace-Bénédict de Saussure, and Charles Bonnet (1781, pp. 18, 36, 64, 70). Unfortunately, his host Bonnet at Genthod showed him only Voltaire's estate at Ferney and Sulzer, who had met Voltaire earlier at Berlin, complained: "Nous ne vîmes point Voltaire. Mr. Bonnet n'a pas sujet de se louer de son voisin" (We did not see Voltaire. Mr. Bonnet is not given to praise his neighbor, pp. 66-67).

In the Alpes-Maritimes, Sulzer visited some of the best exposed geological features and made a few very accurate observations. At La Giandola, he found in the river Roya some "blackish pebbles, known as 'nummulaires', [marine petrifications] which are in fact nothing more than flat and round petrified snails" (pp. 243-244)[12].

In the same mountains, he noticed the various positions of rock-layers and repeated [in refutation of Scheuchzer and Lehmann] that these beds, originally horizontal, had been deposited by muddy waters which originated neither from the Deluge nor some short marine inundation. He stated that all valleys and cliffs are excavated or eroded by torrents and that mountains consisting of rock-layers collapse when their bases are undermined. Only granitic mountains may resist erosion for some time [he was certainly thinking about the Brocken]. When large mountains collapse all at once, layers which were formerly horizontal acquire a different position, ranging from oblique to vertical (pp. 244-245). As an example, Sulzer pointed to a mountain between l'Escarène and Sospel which must have caved in on the northern and southern side: "In the middle, layers have remained in their original horizontal position whereas on the two sides, they are in an oblique position, opposed to each other, resembling the two sides of a hog's back [un toit construit en dos d'âne, p. 246][13].

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[12] These large nummulites of the Middle to Upper Lutetian were probably transported from outcrops on the east flank of the valley. Sulzer followed the main highway from Turin to Nice which in modern French territory passes through the pass of Tenda, the valley of the Roya, Breil, the pass of Bruis, Sospel, the pass of Braus, St. Laurent de l'Escarène, Touët de l'Escarène, l'Escarène, and finally Nice. See Carte géologique détaillée de la France, 1: 80.000, sheet 225, Nice, 1939; Carte géologique détaillée de la France, 1: 50.000, sheets XXXVII-42-43, Menton-Nice with notice explicative, 1968; R. Campredon and M. Boucarut, 1975.

[13] This mountain is the so-called "tectonic shard of the Graia". It builds the mountain called Cime de la Graye (1001 m) which along the highway between St. Laurent de l'Escarène and Touët de l'Escarène displays a spectacular trunk anticlinal structure shown mainly by Callovian to Kimmeridgian thin- to thick-bedded limestones.

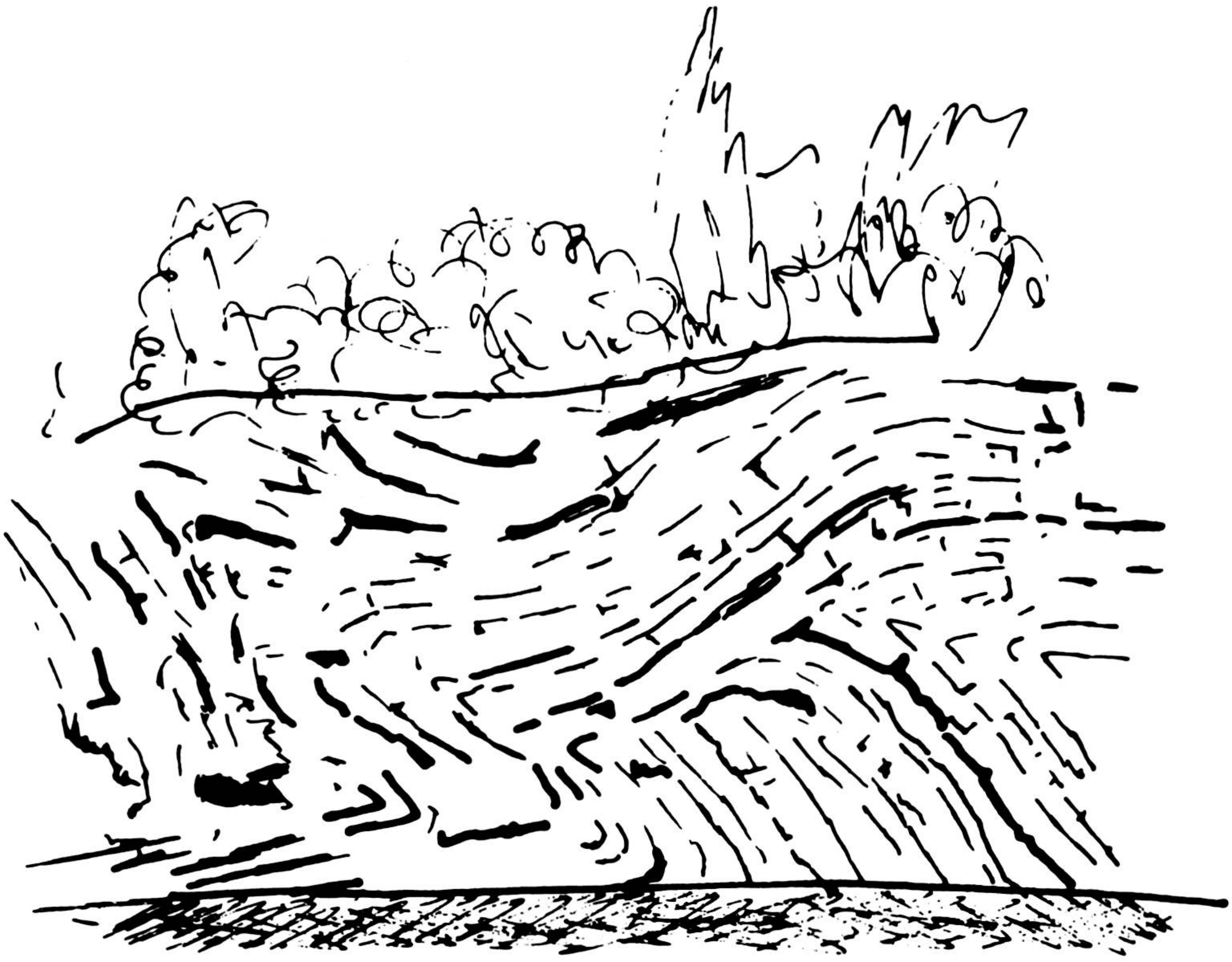

FIGURE 7.

Disharmonic folding in Upper Cretaceous limestones in front of tectonic shard of the Graia, l'Escarène, Alpes-Maritimes (Campredon and Boucarut, 1975, fig. 86, p. 135).

Along the same route, Sulzer observed undulating limestone layers (Figure 7) and said, "While collapsing and falling, the material which was still soft must have become bent under the pressure of its own weight" (p. 246)[14].

Sulzer was furthermore impressed by vertical layers of limestones and shales:

I saw a whole mountain consisting of vertical layers of "pierre à chaux". These layers were in turn of a white and a bluish material so that the whole mountain is separated into parallel bands of these colors. The white layers consist of a solid and hard rock, the others of a softer material which disaggregates in the

[14] Numerous regular alternations of argillaceous limestones and calcareous shales of the Upper Cretaceous (Turonian to Senonian) display in front of the shard of the Graia intense disharmonic folding along the hairpins of the highway between Touët de l'Escarène and l'Escarène (see fig. 86, Campredon and Boucarut, 1975, our Figure 7).

> air. The bluish layers were, therefore, completely destroyed and eroded by rain waters to a depth of some ten feet and the mountain displays a row of deep grooves interrupted by as many ridges (p. 247)[15].

Sulzer believed that each layer represented sediments of muddy waters which had deposited in turn white and bluish layers. This regularity showed, he thought, that floods came from two different areas. He speculated that perhaps the melting of snow from neighboring mountains had caused summer floods whereas warm rains in a different area with less snow had caused winter floods (pp. 247-248). It is interesting to compare this statement with a similar one by Saussure who had pondered on the regularity of alternating limestones and shales during his trip in Italy: "How did deposits of such different materials as limestones and shales produce such constancy and regularity? Did the direction of marine currents, where these mountains were formed, change periodically, and coming from different beaches, did the currents transport deposits of different nature?" (1776, pp. 30-31).

When he returned from Milan by way of the Gotthard, Sulzer found the confirmation for his theory of discharge of hanging lakes in large mountains. He observed both flooded valleys [glacial lakes] and deep valleys which he believed to be the bottoms of former hanging lakes. Passing through the Urseren valley, he saw the Reuss squeeze through a very narrow passage and he thought:

> If this narrow passage were blocked by a dam as high as the surrounding mountains, the valley would change into a lake several thousand feet deep. The Alps display many such examples of flooded valleys, but here, one sees evidently that the actual exit was once closed so that it seems obvious that the Urseren valley is the bottom of a former lake which was some 5000 feet above sea-level. In the least resistant areas of the mountains bordering this lake, the waters excavated a canyon, either little by little, or all at once, through which they escaped. Thus was formed the gorge which leads to the plain. The pebbles and the earths transported by the river are now accumulated in the plain and form the earth-crust at the foot of the mountains (pp. 335-336).

Sulzer's theory of catastrophic discharge of hanging lakes written in 1762 and confirmed in 1780, called here Hypothesis B, can be represented by three stages (Figure 8) if the first stage of deposition of layers forming the large mountains, similar to the first stage in Figure 3, is omitted.

1. Uplifting and arching of the first layered mountains is accompanied by the formation of hanging lakes which become filled with unconsolidated sediments. The waters of the lakes together with these sediments are catastrophically discharged

[15] Alternations of argillaceous limestones and calcareous shales (pierre à chaux) in a vertical position, with strong differential weathering, form an anticinal axis at the place called Prat just before reaching l'Escarène along the highway described in footnote 12. These limestones and shales have been extensively quarried in the Alpes-Maritimes for cement manufacturing.

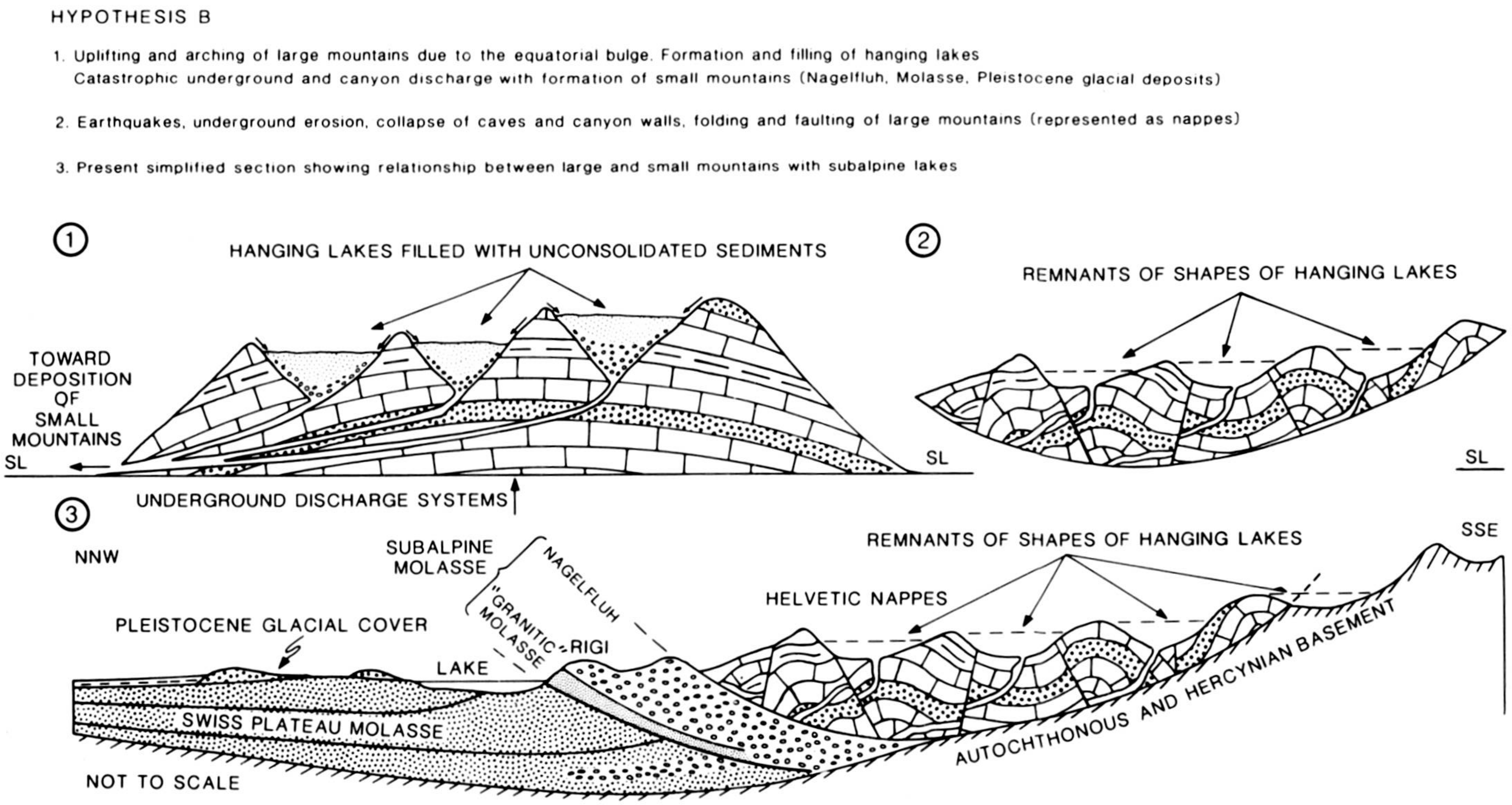

FIGURE 8.

Interpretation of Sulzer theory of the earth (1762), Hypothesis B.

through underground systems at the base of the lakes and through newly formed canyons thus depositing in the adjacent sea all the debris forming the small mountains.

2. Earthquakes, underground erosion, collapse of caves and canyon walls lead to faulting and folding of the stratified mountains. Traces of empty lake basins are preserved in the morphology [tectonic and glacial lakes as observable today].

3. The present situation shows small mountains consisting of Nagelfluh, Molasse, and Pleistocene glacial deposits at the foot of large mountains as well as the location of peri-alpine lakes which are interpreted as excavation products of the catastrophic discharge of hanging lakes.

DESMAREST'S REACTIONS TO SULZER'S THEORY OF HANGING LAKES

In his *Géographie-Physique,* Desmarest accepted tacitly Sulzer's antidiluvialist theory of 1746 giving a long abstract of most of Sulzer's ideas and denouncing Scheuchzer as having propagated diluvialist ideas more than anyone else (1794-1795, pp. 510-524 on Sulzer, pp. 432-436 on Scheuchzer). However, he did not accept Sulzer's theory of hanging lakes (1762) and did not mention his last work of 1780. Such a theory did not fit into Desmarest's ideas on normal fluvial erosion. He also wondered how Sulzer could propose that calm and sedentary waters from those lakes could have destroyed their barriers, make deep openings, and discharge silt and other material over the lowlands during a sudden inundation (1794-1795, pp. 523-524).

We believe that Desmarest's refutation does not include the possibility of lake basins which were formed, as Sulzer believed, when the first mountains emerged as islands, namely as layered mountains with irregular surfaces due to the falling down of unstable masses. These first mountains consisted, therefore, of high peaks with intervening deep valleys in which the waters of rain and springs could collect. In fact, in the context of the Alps, Sulzer's deep lakes are empty basins or lakes held by rocky thresholds which can be tectonic or overdeepened glacial valleys. In regard to a sudden catastrophic discharge of these lakes, Sulzer had given the mechanism which prompted such a discharge although Desmarest said he had not, namely that a mere shaking of an earthquake could produce a fissure at the base of one of the barriers through which the waters could escape.

CONCLUSION

Sulzer is today forgotten because he was not understood by his contemporaries. The main reason is certainly the fact that unlike Lehmann, Sulzer stumbled into some very difficult problems in geology. Indeed, Molasse, glacial deposits, and "nappes" were going to puzzle several generations of naturalists after Sulzer. Furthermore, d'Holbach's misinterpretation of Sulzer's theory contributed to its neglect because, for many years to come, the *Encyclopédie* by Diderot provided the most up-to-date information of the "new sciences" and d'Holbach's interpretation instead of Sulzer's theory was being read.

Today, Sulzer's two theories strike as innovative in fields where other naturalists of his time did not venture or did not find any better explanation. His theory on the origin of large mountains according to "mathematical" principles of the equatorial bulge went clearly beyond a similar theory proposed by Bourguet at about the same time. It was based on the latest discoveries by Maupertuis and explained large mountains by causes others than those mentioned in the Bible. It has not been recognized that Sulzer's first theory was responsible for many of Lehmann's ideas on the origin of his layered mountains (Flötz-Gebürge) and thus represents an important step in the progress of geological ideas. Sulzer's second theory on a catastrophic discharge of hanging lakes in large mountains accounted for glacial deposits in the plains of Switzerland and Germany and is certainly not any more peculiar than Saussure's hypothesis of a "débâcle". In fact, his theory explained, without any reference to the Deluge or some great flood, the great amount of debris, later to be called Diluvium, until a better answer was found. In his latest work, he particularly explained Alpine morphology of hanging lakes as well as structural effects on mountain layers after catastrophic discharge of these lakes.

This study shows, in particular, how Sulzer's ideas on geological phenomena progressed through time. In his first paper, he seemed unable to account for the formation of small mountains by means others than the Deluge or a general inundation. Like his predecessors, he also wrote that inclined layers are caused by earthquakes or collapse. In his second paper, he introduced new interpretations for both concepts. His theory of catastrophic discharge of hanging lakes explained the occurrence of debris of large mountains everywhere in the plains. Thus he no longer believed in a general inundation which had flooded the highest mountains but explained, for instance, transportation of pebbles to the Rigi by waters escaping from nearby hanging lakes. He added the idea that upon collapse of large mountains, during the discharge of hanging lakes, originally horizontal layers acquire an inclined position. He probably had in mind layered large mountains in the Alps but when writing the essay, he was unable to point to any example in Germany because the Brocken is a granitic mountain. In his third paper, Sulzer not only confirmed that the Urseren valley was a clear example of a former hanging lake but he also observed in the Alpes-Maritimes folding of layers in large mountains. He was now able to demonstrate that inclined layers in large mountains are the effects of catastrophic discharge of hanging lakes which lead to the sudden collapse of a mountain with resulting folding and faulting of its layers.

In short, throughout his life, and in spite of being an "Amphibium", he remained at the forefront in geology, starting with a "mathematical" theory on the origin of large mountains, rejecting diluvial theories, believing in a long geological time, describing carefully small mountains consisting of fragments of the large ones, and ending with a clear description of structural features encountered during his travels in the Alps.

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