From: G. Gohau, A History of Geology (Rutgers: New Brunswick, 1990).

Chapter 6

On Mountain Building

Exploring the Mountains

In the eighteenth century, particularly during the second half, nature was discovered by the public at large. Jean-Jacques Rousseau not only set the fashion for gathering plants, but in his novel, *La Nouvelle Héloïse* (1761), he also led his readers to the discovery of mountains. Indeed, in his description of the Valais in Switzerland, he evoked alpine landscapes that appeared stranger to many of his contemporaries than do those of the moon to us: "Now huge rocks were hanging in ruins above my head, now I was submerged by the thick mist of high and roaring waterfalls, now an endless torrent disappeared into an abyss close to me, the depths of which no eye would dare to explore."[1]

Whereas Rousseau traveled "in ecstasy through these little known places which are so worthy of admiration," Horace-Bénédict de Saussure, at the age of twenty, promoted a daring project: the ascent of the highest European summit, the dangerous Mont Blanc, which towers above the valleys of Chamonix and Courmayeur. He accomplished the task only a quarter of a century later.

In August 1787, at the head of a field party, he set foot on the snow-covered summit. Jacques Balmat, a guide from Chamonix, and the young doctor Paccard had reached the much desired peak a year earlier, but to athletic achievement Saussure added scientific observations (see box).

The Climbing of Mont Blanc by H.-B. de Saussure

Finally, the moment I had wished for arrived when I started out on August 1 [1787], accompanied by a servant and eighteen guides who carried instruments of physics and all the paraphernalia I needed. My older son had wished very much to come along; however, I was afraid that he was not yet robust enough. . . . He stayed at the priory, where he carried out careful observations similar to those which I made on the summit. . . .

We reached at a quarter till two the summit of the mountain La Côte, the place where we were to spend the night. The first day had thus not been long. It had taken us only six and a half hours from the priory to our first camp. . . .

The following day, August 2, in spite of our eagerness to leave very early in the morning, so many disputes arose between the guides about the distribution and the arrangement of their loads that we were actually off only at six thirty. . . . We began to cross the glacier, opposite the granite boulders where we had taken shelter for the night. . . . It took us almost three hours to cross this dangerous glacier, although it is hardly a quarter of a league wide. . . .

After a one-hour walk, we had to coast along a huge crevasse. It was over a hundred feet wide, and we could not see the bottom. [After having crossed the crevasse, then dined and gotten over a first plateau,] we climbed for almost an hour on a 34° slope and finally reached the second plateau, where we planned to spend the night. . . .

At the same time, L. F. Ramond de Carbonnières (1755–1827) reached Mont Perdu, a summit of the Pyrenees. As with Saussure, his ambitions were above all scientific. Mountains now became an attraction for meteorologists (Saussure carried with him barometers and hygrometers) and geologists. They now considered mountains worthy of detailed studies.

As mentioned above, Steno placed rock layers without "heterogeneous bodies" at high altitudes. Although today this statement may seem out of place in the writings of the founder of the principles of stratigraphy and tectonics, it soon struck neptunists as logical.

Telliamed

Benoît de Maillet (1656–1738), French consul at Cairo, has won a place in the history of natural sciences through an anonymous

(continued)

The following day we first crossed the second plateau . . . from there we climbed to the third. . . . After a walk of two and a half hours, we reached the boulder that I call the left shoulder or the second staircase of Mont Blanc. There I could see an immense horizon completely new to me. . . .

From Chamonix I had measured the elevations of the different parts of the mountain, and hence knew that only about 150 toises were left for me to climb. . . . I hoped therefore to reach the summit in less than three quarters of an hour; however, the thin air gave me greater difficulties than I had anticipated. Finally, I was forced to catch my breath every fifteen or sixteen steps. . . . At last I reached the goal I had been striving for so long. But during the two hours of this difficult climb I had already looked at almost everything that I finally saw from the top, so that the arrival was no longer a sensational event.

Nevertheless, the view of the mountains gave me a vivid satisfaction. . . . It seemed like a dream when I saw these needles of Midi, of Argentière, of Géant, the basal slopes of which had been for me so difficult and so dangerous to reach.*

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*Horace-Bénédict de Saussure, *Voyages dans les Alpes, précédés d'un essai sur l'histoire naturelle des environs de Genève*, 4 vols. (vol. 1, Neuchâtel: Samuel Fauche, 1779; vol. 2, Geneva: Barde, Manget & Cie, 1786; vols. 3 and 4, Neuchâtel: Louis Fauche-Borel, 1796), vol. 4, § 142, 147, 155–157, 160, 163, 168, 171, 175–176.

manuscript he put into circulation in the 1720s under the title "Nouveau système du monde ou entretien avec Telliamed" (New system of the world or discourses with Telliamed). Telliamed is his name spelled backward. The work was only published in 1748, ten years after his death.[2] This diplomat's thesis was quite daring: he believed that humans had descended from marine ancestors. As proof, he offered travelers' tales of sea monsters with human traits. Some historians of transformism have considered this author a forerunner of Darwin, although the legends and stories given as proofs of Maillet's extravagant theory seem a little far-fetched and hardly worthy of being taken seriously. However, his geology was a great leap forward and places his views clearly at the beginning of the distinction between two successive kinds of mountains.

His main idea is this. The sea level keeps getting lower; therefore, all terrestrial species descended from marine ancestors that underwent transformation during the diminution of the sea. His great audacity lies in measuring time by thousands of centuries and in believing that the diminution of the sea lasted 500,000 years. (A contemporary of Maillet, under the pseudonym of the "Turkish spy," a name assumed by various authors, also reckoned enormous time spans.) However, of interest to the geologist is Maillet's use of that time. As the sea diminished, mountains emerged that were increasingly younger and less elevated.

The oldest mountains, which he called "primitive," contained no fossils. However, Maillet's reasons for adopting the Stenonian concept were different from Steno's. Maillet did not believe in a creation of the world. According to him, the earth had undergone previous cycles of drying up and rehydration; mountains were primitive only in the sense that they were old compared to the present world. Nevertheless, marine organisms could live only in shallow shoreline water. As a result, when the sea level was much higher, these mountains were too deep under water to allow any sort of life.

How were these mountains formed? By marine currents at the bottom of the ocean. The materials accumulated there derived from the reworking of the ashes from an earlier extinguished sun whose indurated crust formed the ocean floor. During the shrinking of the waters, the highest parts of the mountains emerged and life appeared in these areas. New deposits were formed from the remains of living organisms, and hence new mountains were born. They leaned against the older ones and were not as high.

The evolution of the earth's crust according to Maillet's system has been interpreted by A. V. Carozzi (see figs. 6.1 and 6.2).[3] The diagrams show successively younger mountains leaning against older ones; that is, a decrease in elevation from the oldest to the youngest mountains. The modern reader who has learned that young mountains are generally high because they are not eroded whereas old mountains are lower because they were peneplained through time may be surprised by this arrangement. Nonetheless, it is worth noting that Maillet's interpretation does explain some mountain structures better than the usual modern explanation of the topographic relationship between old and young mountains.

A Cross-section of the Alps

Up to this point, all we had to do to follow the debate between early geologists was accept that certain rocks are fossiliferous. From now

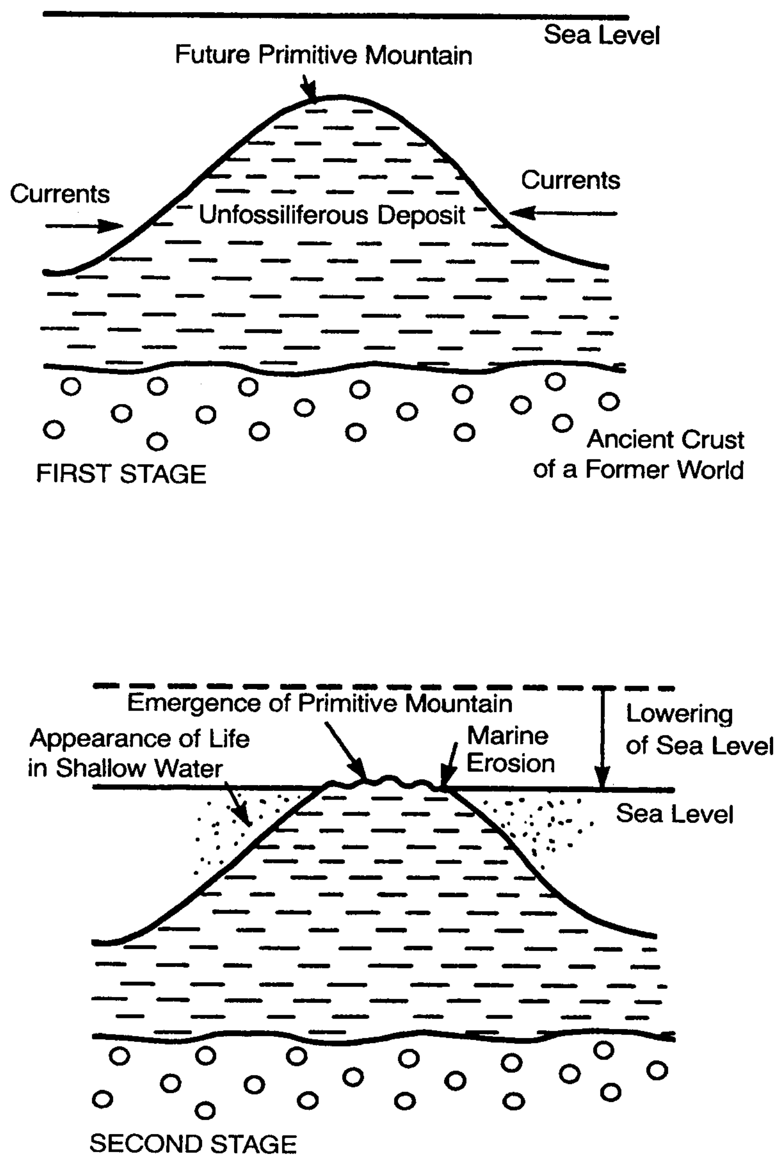

Figure 6.1. Stages 1 and 2 of the Formation of Mountains According to the Concept of B. de Maillet (Modified from Telliamed, *1748, trans. A. V. Carozzi, 1968, reproduced by permission of the University of Illinois Press, Urbana).*

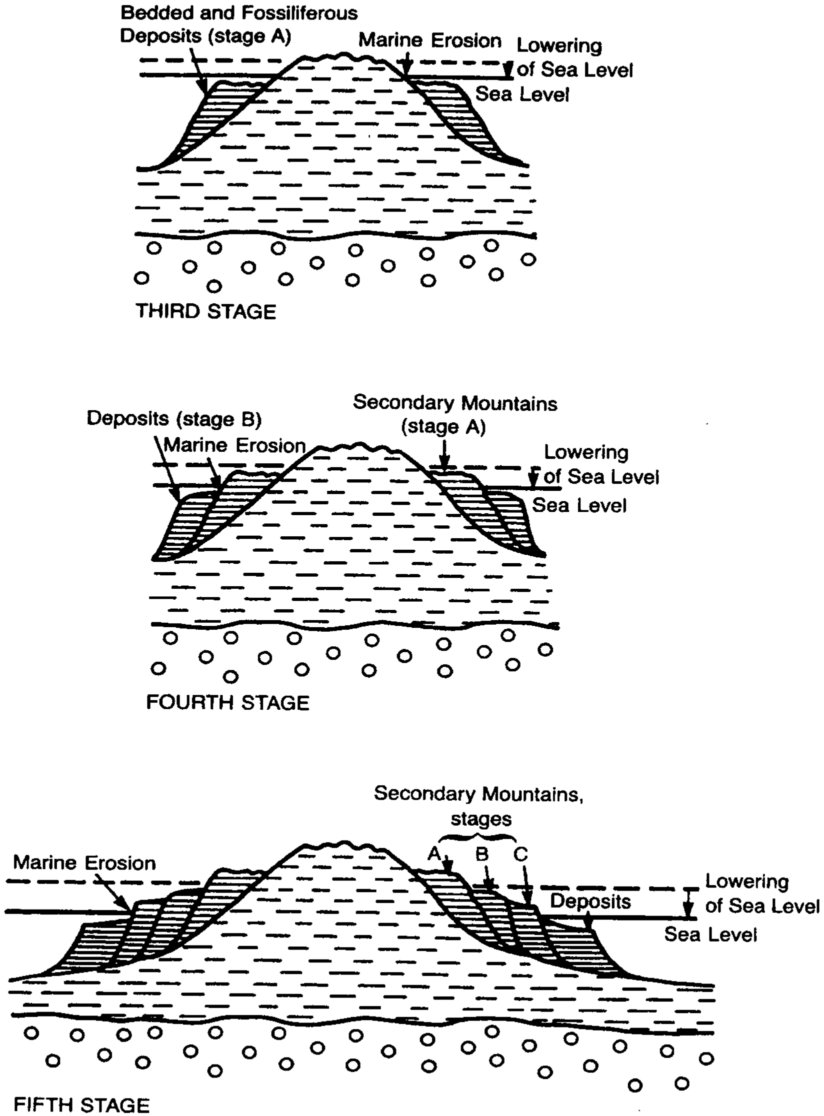

Figure 6.2. Stages 3 through 5 of the Formation of Mountains According to the Concept of B. de Maillet (Modified from Telliamed, *1748 trans. A. V. Carozzi, 1968, reproduced by permission of the University of Illinois Press, Urbana). The five diagrams correspond to five stages of successive lowering of sea level.*

on, more knowledge is needed. Let us pretend to go westward from Mont Blanc along a straight line. We would encounter a few other summits higher than 4,000 meters before crossing the High Calcareous Alps, which are at a lower elevation, and reaching the peri-Alpine plains and plateaus. Mont Blanc and the adjacent summits consist of igneous and metamorphic rocks (granite, gneiss, and others), which are neither fossiliferous nor stratified. The High Calcareous Alps, on the other hand, show folded fossiliferous layers. This situation is more or less as Maillet describes it, and occurs all along the Alpine chain.

Maillet's interpretation fails us, however, when we consider the origin of these two types of mountains. Maillet believed that the older mountains, those consisting of igneous and metamorphic rocks, such as Mont Blanc, acquired their present height during their original deposition. According to modern theories though, these mountains underwent two successive orogenic uplifts. One occurred near the end of the **Paleozoic era,** some 250 million years ago when all of middle Europe was transformed into a vast mountain chain called **Hercynian mountains.** The present topography is not a residue of these huge Hercynian mountains because these were peneplained at the end of the Paleozoic era, about 225 million years ago. Only their substratum remained, and new oceans poured over these lands. Erosion destroyed the upper parts, and today this substratum, or basement, consists only of the deeper parts of the Hercynian mountains, those transformed into igneous and metamorphic rocks by heat and pressure.

The second orogeny began toward the end of the **Mesozoic era** when the circum-mediterranean chains were formed, stretching from the Pyrenees to the Taurus and including the Alps, the Carpathians, the Atlas chain, and others. Mountain building continued during part of the 60 million years of the **Cenozoic era.** This uplifting exhumed the cores of the old Hercynian chain; from these cores the "cover" of younger layers (High Calcareous Alps, for instance) slid down as gravity thrusts (**gravitational sliding**).

When I said earlier that old mountains are often lower than new chains, I was actually not referring to the Alps but to such old mountains as the Massif Central or the Vosges in France or the Appalachian Mountains in the United States, which owe their present relief to movements more or less contemporaneous with the Alpine orogeny. These mountains—as well as the Alps—were eroded and

Basement and Sedimentary Cover

When sedimentary layers rest **unconformably** on folded metamorphic rocks that were injected by igneous rocks during a former orogeny and thereafter peneplained by erosion, the upper layers are called sedimentary cover and the lower ones basement. The Central Massif and the Armorican Massif thus form the exposed parts of the basement of the Paris Basin.

When an area undergoes tectonic stresses, the previously highly folded and strongly crystallized basement of igneous and metamorphic rocks breaks up in a brittle fashion, whereas the more ductile sedimentary cover is deformed. If stresses are powerful and if layers conducive to sliding exist at the base of the cover (for instance, very ductile clays), the cover separates from the basement and undergoes deformations completely independent from those of the basement. For example, the High Calcareous Alps represent the sedimentary cover of the igneous and metamorphic rocks of Mont Blanc, which slid away northwestward as gravity thrusts, leaving behind the uplifted basement.

peneplained at the end of the Paleozoic era and uplifted only recently, but of course not as much as the Alps.

The Wonders of High Mountains

The interest in high elevations did not always have a rational basis. At the end of the eighteenth century, many people were forever praising mountains for sentimental or aesthetic reasons. J.-A. Deluc called them "a wonderland" where "all is beautiful and lavish."[4] Déodat de Dolomieu, even more enthusiastic, did not hesitate to describe all mountain folk as "good fathers, good sons, good husbands, and good parents."[5] He showed quite incidentally the ambivalence that mountains could engender in the human spirit. "Now," he said, "you might believe that you are attending the creation of the world, now you seem to look at its ruins."[6] Youth and old age seemed to meet in this strange and unfriendly world (all travelers suffered from high altitude), which linked the purity of childhood to the decrepitude of old age.

If "reason" invited naturalists to search in mountains for traces of the first ages of the history of the world, they often took as their starting point the view that the earth was initially covered by a chaotic

ocean, "formed," as the Bible says, "by means of water." Although Maillet was far removed from religious preoccupations, his neptunist theory of the origin of mountains still bore the imprint of this cultural theme.

He believed also, as did many others, that old mountains were of high elevation. In the case of Mont Blanc this statement still holds; it is not paradoxical to climb the Alpine summits in order to find the oldest deposits of the history of the earth. But the old granitic summits of the Alps reached their present-day location through uplifting, a concept Maillet never used.

All through the eighteenth century, mountains were generally believed to be simply superposed layers formed at the bottom of the ocean—hence the name of neptunism given to this concept. Primitive mountains were considered to be the summits of uneven deposits, or, in other words, the ancient layers taken as a whole formed primitive mountains. In 1752 the geographer P. Buache wrote an essay "On the kind of structure of the globe, composed of mountain chains which cross the oceans as well as the lands," a title reminiscent of the concept of the earth's bone structure used in earlier centuries.[7] The term *mountain* was often taken in a large sense to describe not only the highest peaks but also the entire deposit of the same age. Closer to the neptunist concept, the German language used the same word, *Gebirge* (or *Gebürge*), for both the mountain and the subterranean rock layers. In reality, primitive mountains described by neptunist authors referred to what is called today the Hercynian basement. Although their interpretation was erroneous, they did correctly observe the distinction between primitive mountains and the sedimentary cover.

The weakness in neptunism was the need to assume that summits of 4,000 meters or more were once beneath sea level, a situation requiring huge oceanic masses. For Maillet, who measured time by thousands of centuries, this water needed merely to dry up. However, authors who followed the Scriptures faithfully were burdened by the problem of having only thousands of years to accomplish this.

Volcanic Mountains

In an attempt to overcome the problem of lowering sea level, the Italian Lazzaro Moro (1687–1764), contemporary of Maillet, stated that the primitive ocean did not rise more than 175 *toises* (about 350 meters) above its present level. He proposed that any mountains with strata and fossils higher than this elevation had been uplifted.[8]

He, too, distinguished two classes of mountains. The first ones "originated in the bowels of the Earth when the surface area where they were born was still covered by water and not burdened by terrestrial materials." In other words, erosion had not begun because no island had emerged. These mountains, which Moro called "primary," were formed by "large masses of rocks" and were thus not stratified. After their emergence, erosion produced materials that were deposited at the bottom of the ocean and were uplifted in turn to form "secondary" mountains. According to Moro, they differed from the first ones in their structure, which consisted "almost entirely of superposed layers."[9]

To explain uplifting, Moro referred to recent volcanic eruptions. He mentioned that an island emerged in 1707 and reminded his fellow Italians of the birth of Monte Nuovo in 1533, in the Bay of Naples, in the middle of the Phlegraean Fields, very close to Vesuvius. He added, since "the same causes produce the same effects," what happens today must have happened during the first periods of the history of the world.[10]

Moro thus spoke like a uniformitarian, and his theory seemed to offer a way out of the neptunists' dilemma. We might therefore expect that it would convince his contemporaries. Nothing of the sort happened. His attempt as a vulcanist reaped no success, and neptunism continued to rule among naturalists. It was only in the nineteenth century, when Charles Lyell raised the uniformitarian approach to an important concept (chapter 11), that Moro's ideas were belatedly appreciated.

The Retreat of the Sea

We must admit that the neptunistic view also offered good arguments that could claim to rest on observed facts. In 1724 the physicist Anders Celsius (1701–1744), known for his invention of the Celsius scale, measured the level of the Baltic Sea. He placed benchmarks to measure variations of sea level.[11] One of the measurements made in 1731 by Celsius was used in 1747 to show that sea level had lowered in the Gulf of Bothnia.

The famous naturalist Carl Linnaeus adopted Celsius's thesis and published in 1744 an essay called *The Growth of the Earth*, in which

he explained that "the entire *land* was during *the Earth's youth drowned in water* and covered by a vast ocean *with the exception of one island*."[12] His goal was essentially biological: he placed the island at the equator, without great concern for geographical veracity, where it was to receive a pair from each species or one individual from hermaphrodites. However, and this is the interesting point, the famous botanist thought he had to calculate the retreat of the sea. He said that it had fallen 5 to 6 feet over a hundred years so that the sea level had dropped 240 to 300 feet in six thousand years. However, Linnaeus made a mistake of the order of ten in his calculations, writing that the sea had retreated 2,700 feet. Strange slip of the pen. He corrected it later to 240 feet, which reduced the mountain to an anthill.[13] There is no better way to demonstrate the inconveniences of traditional chronology.

These examples of eighteenth-century geological theories demonstrate how difficult it was to keep geological phenomena in the framework of biblical chronologies and to give them, at the same time, the magnitude required by observations of natural phenomena. The calculation error of Linnaeus reveals the obstacle he and his contemporaries encountered. Maillet overcame it easily by breaking away from short chronologies. Moro solved the problem in another fashion by abandoning neptunism in favor of vulcanism. Nevertheless, these hypotheses remained isolated and unused because both required a definite break with generally accepted ideas. Most naturalists of that period continued to associate biblical chronologies and neptunism, thus refusing both immense durations and uplifting movements of the earth's layers.

Classification of Mountains

The mid-eighteenth-century author who contributed most to the establishment of the theory of two (or three) classes of mountains was the German mineralogist Johann Gottlob Lehmann (1619–1767). His book, *Versuch einer Geschichte von Flötz-Gebürgen* (Essay on a history of secondary mountains), published in 1756, was translated into French three years later.[14]

Lehmann said that in primitive mountains, which he called *Gang-Gebürge*, "strata are not horizontal but either perpendicular or diagonal. Beds are not as thin and varied as those in secondary mountains" (*Flötz-Gebürge*).[15] If any rare fossil shells occur in primitive mountains, they rest on the surface and are not incorporated inside the rock. Finally, these mountains are rich in mineral deposits, they are of high elevation, and they have steep slopes. Secondary mountains, or stratified mountains, are formed by horizontal, thin, and regular layers; they contain fossils buried in their rocks; they are poor in minerals, of low elevation, and their slopes are gentle. A third class of mountains exists, more insignificant yet, which Lehmann hardly described.[16]

Lehmann thus came closer to Maillet's than to Moro's ideas with respect to the origin of mountains. He believed that all mountains were formed in the oceanic waters and remained in the same location where they were deposited. The only difference from Maillet is Lehmann's belief that the two main classes were formed during successive advances of the sea.

In France, these ideas spread quickly thanks to the rapid translation of the *Versuch*[17] and the lively personality of the translator, who was no less than the baron d'Holbach, friend of Diderot and anonymous author of audacious philosophical works, such as *Système de la nature*, in which he defended atheism.[18] Interested in geology, d'Holbach was in charge of writing articles concerning the earth sciences in the *Encyclopédie*.

Guillaume-François Rouelle (1703–1767), friend of d'Holbach, supported similar ideas. In his lectures at the Jardin des plantes, he added a little bit of mineralogy and geology to chemistry and distinguished an "ancient Earth" with tilted layers, "which has always existed the way it is now," from a "new Earth," which was deposited on top.[19]

The same concept was used again by Giovanni Arduino (1714–1795), a mineralogist and chemist who distinguished primitive schistose mountains from secondary limestone mountains, and the latter from more recent ones, consisting of sand and clay, which he called tertiary mountains.

For all these authors, two characteristics were associated: decrease in elevation and change of the nature of rock formations from one class of mountain to the other. The nature of rocks and their location posed some problems. Lehmann identified primitive mountains by their veins and poor stratification. Undoubtedly, he meant granitic mountains, which are not stratified but in which some excellent observers believed they could see more or less regular layers (perhaps from seeing almost parallel fissures). Arduino did not find

any granite in his primitive mountains in the Vicentino, but, knowing that they existed elsewhere, he wondered whether granite might not be underneath schists. In secondary mountains, limestone seemed to be the main constituent.[20]

The concept established by the three authors, each one for his own country, called for generalization. Because the second half of the eighteenth century saw the exploration of large mountain chains, the time was ripe to test in the field the model that worked for the border of the old Hercynian massifs in Central Europe. The Alps showed a rather similar arrangement and, as mentioned above, massifs of igneous and metamorphic rocks topographically dominate limestone massifs. Indeed, Saussure had no problem finding the arrangement of granite, schistose rocks, and limestone.[21] Only the Pyrenean chain seemed to present an anomaly.

The Case of the Pyrenees

Pierre Bernard Palassou (1745–1830), who explored the Pyrenees in the early 1780s, found at first the same general arrangement.[22] However, in 1782 Déodat de Dolomieu (1750–1801) maintained that the center of the chain was limestone and not the expected granite. He was pleased because he opposed "systems" and deplored that one was "wanted to subject nature's productions to a certain order."[23] He was, by the way, an original thinker who held a notable place in geology at the end of the century. Without any doubt, he would have left an important work had he not dispersed his energy and become mixed up with various, sometimes obscure adventures. A serious quarrel with the Order of the Knights of Malta, to which he belonged, kept him in prison for twenty-one months beginning in 1799. He left prison very weak and sick and died in 1801 at the age of fifty-one, just when he had started to take up geological observations again.

However, Dolomieu had based his ideas on only one brief visit to the Pyrenees. It was one of his friends, Philippe Isidore Picot de Lapeyrouse (1744–1818), who confirmed Dolomieu's ideas in the last years of the eighteenth century after having observed that "primitive limestone," a "contemporary of granite," did "not contain the least trace of organic beings"—the undeniable proof of its old age.[24]

Another Pyrenean geologist, L. F. Ramond de Carbonnières, refuted this opinion. According to him, limestone was not a primitive but a secondary rock formation. Therefore, it must be fossiliferous everywhere. He challenged Picot de Lapeyrouse by proposing the two climb Mont Perdu, the main summit of the limestone chain, together.

The trip got underway, and Ramond won twice. Not only did he find the predicted fossils, but his companion could not follow him to the top of these unfriendly mountains. This was the year 1797, ten years after Saussure had reached the summit of Mont Blanc. Ramond was able to shout in triumph: "There are marine bodies on the ridge of the Pyrenees and on the peak which dominates all Pyrenean mountains."[25]

As a result, limestone mountains were no longer regarded as primitive mountains. They were younger than the granitic axis of the chain and the two adjacent schistose chains at its flanks. The Pyrenees thus became part of the generally accepted arrangement. The only anomaly they presented was the elevation of the parallel ridges: the northern adjacent schistose chain is highest at Vignemale, right above the axis, whereas the Vignemale itself is dominated by Mont Perdu. The order was preserved though the hierarchy between mountains was slightly amiss. Ramond attributed this abnormal altitude to an accidental accumulation, and the Pyrenean chain joined the geologists' list of mountains formed according to the common rule.

Universal Order?

Before closing this chapter, a major problem has to be emphasized. It was generally accepted that, if the Pyrenees indeed showed the same order in the arrangement of layers as the Alps—granite, schists, and limestone—and if exploration of other mountains throughout the world showed that they belong to the same class, then the arrangement of strata had to be identical everywhere on earth (Pallas examined the Urals in the 1770s, and Humboldt crossed the Atlantic a little later to study mountain chains in South America).[26] The order of superposition of rock formations was therefore believed to be universal. As a result, it no longer seemed necessary to establish this order in remote and unfriendly mountains. Generalization was believed possible even when it was based merely on data already collected so long as that data seemed significant enough to prove the universality of succession. New observations would only confirm what was already probable.

If that were the case, did the layers of the earth still remain archives? The role of archives is to provide information about events that can be known only through them. However, if the order were universal, documents found in a limited area could give information about the history of the entire earth.

Neptunists were thus edging toward a system where archives would again become useless. And this in spite of Maillet, who had stressed the importance of geological relicts of the past. Maillet's view seems to have been neglected by historians of geology, and it is in fact rather unexpected coming from an author of a theory of cycles who was more interested in finding regular and repetitive events than random and unique ones. After noticing that in general the earth perished in flames at the end of each cycle, he wrote: "If we could dig down to the center of our globe, and go through the various arrangements of the materials forming it, we should be able to judge by means of these investigations whether it has been several times completely covered with water after having been inhabited, without having been the prey of flames. In such a case, one should find inside the globe all the remains of several superposed worlds."[27]

In other words, if the cycles were incomplete instead of following each other in an identical fashion, they would add their remains in a stratigraphic column. This theory foreshadowed the concept of sedimentary cycles used at the end of the century. However, Maillet stopped there. His theory as a whole did not lead him to pay attention to this progressive construction of the earth. Such a theory would have to stress the irreversible nature of the earth's history.