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HORACE-BÊNÉDICT DE SAUSSURE, A FORERUNNER IN 1794–95 OF EXPERIMENTAL WEATHERING

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Abstract—In a hitherto unpublished manuscript dated 1794–95, H.-B. de Saussure described three types of rudimentary laboratory experiments on weathering, each one lasting about 4 hours, undertaken on samples of jade, serpentine, feldspar, and mica schist. He submitted these samples to dry heating, heating with continuous addition of water, and heating with periodic addition of water. Experimentation was performed at temperatures of the order of 200–250°C, and Saussure seems to have realized that a reasonable increase of temperature was necessary for laboratory simulation of long-lasting geological processes. No changes were observed during dry heating whereas increasing alteration was noticed in the presence of water, particularly when heating was combined with periodic wetting. He concluded that these tests demonstrated his preconceived idea that weathering of minerals (mostly silicates) resulted from alternating periods of drying and wetting. This concept is basically very close, if not identical, to that underlying modern ideas on seasonal weathering.

Key Words—Experimental weathering, Jadeite, Serpentine, Feldspar, Mica Schist, Goethite, Smectite, Talc, Halloysite, Kaolinite, History of mineralogy.

INTRODUCTION

Horace-Bénédict de Saussure (1740–1799), the famous naturalist from Geneva, Switzerland, is well known for his extensive field studies in the Alps (Saussure, 1779–1796). At the end of his career as a geologist, he reached the revolutionary idea that the formation of folded mountains, the Alps in particular, resulted from processes of horizontal compression which he reproduced in the laboratory almost a century before experimental geology was born (Carozzi, 1989). Saussure extended his keen interest in experimentation to physics, meteorology especially, by creating and having built a variety of portable instruments such as the first magnetometer, cyanometer (to measure the intensity of the blue color of the sky), and diaphanometer (to measure the degree of transparency of the air) as well as improved versions of hygrometers, thermometers, and barometers (Freshfield, 1920; Barry, 1978). In mineralogy, he worked extensively on a classification of rocks and minerals based on their behavior by blowpipe assay. Consequently, Saussure, with his combination of field observations in high mountains and talent for experimentation, was highly interested in the weathering of rocks and minerals and undertook a series of tests on experimental weathering. Based on the results of his tests, Saussure felt that he had demonstrated his preconceived idea that heat alone was an insufficient process but that alternating periods of drying and wetting were responsible for weathering. This concept is very close if not identical to the modern idea of seasonal surficial alteration.

Because of its ground-breaking nature, Saussure's manuscript, written with the chemical and mineralogical terminology of the end of the 18th century, was translated and the results compared with modern ideas on chemical weathering.

SAUSSURE'S EXPERIMENTS

The six-page manuscript written in Saussure's own handwriting (Figure 1 shows the first page) is entitled "Experiments on the decomposition of fossils by the combined action of water and fire" (Saussure, 1794–95). In the 18th century, the designation of "fossil" was given to rocks and minerals as well as fossil organic remains, and the designation of "fire" meant heat. Saussure began by suggesting that valuable information could be obtained from laboratory experiments which might, under controlled conditions, accelerate the weathering of rocks and minerals because he postulated that such a process resulted mainly from alternating (i.e., seasonal) periods of wetting and drying.

In his experiments, Saussure used very thin crucibles of Wedgewood porcelain and a coal fire. Although the crucibles became red very quickly, temperatures remained in the order of 200–250°C, an estimation based on other comparable experiments he undertook on minerals and rocks. He understood, like modern experimental petrologists, that the simulation of processes operating under atmospheric conditions and during a long geological time, required special procedures. In particular, he raised the temperature to accelerate reaction rates in order to obtain tangible results within a reasonable laboratory time.

Accordingly, Saussure undertook a preliminary test. He put small fresh fragments of marble containing abundant crystals of delphinite (an 18th-century name

Expériences sur
la décomposition des fossiles par
l'action réunie de l'eau et
du feu
1794 et 1795

§ 1.
Persuadé qu'on acquerreroit des
lumières intéressantes si l'on pourroit
à son gré accélérer la décomposition
atmosphérique des fossiles, et que
cette décomposition étant [l'effet de]
principalement l'effet des alternations
d'humidité et de sécheresse, je mis
dans un petit creuset des petits fragments de cette roche
mêlée de calcaire et de delphinite des
bords du lac qui a formé à l'air une croûte
d'un pouce et plus d'épaisseur. Je
fis rougir ce creuset et j'y injectai
de l'eau par intervalles; mais ennuyé
de ces injections je suspendis au-dessus
du creuset un entonnoir garni
de plusieurs feuilles de papier gras
par où l'eau ne tomberoit que par gouttes
à travers, et au bout de trois quarts d'heure
je vis que la pierre commençait à se
noircir à la surface. Mais cet appareil n'était ni assez actif ni assez
commode pour que l'on puit suivre à des expériences telles que je les désirois.
§ 2. En conséquence, j'ai pensé d'employer
l'appareil de M. Lavoisier pour la
décomposition de l'eau par le carbone.

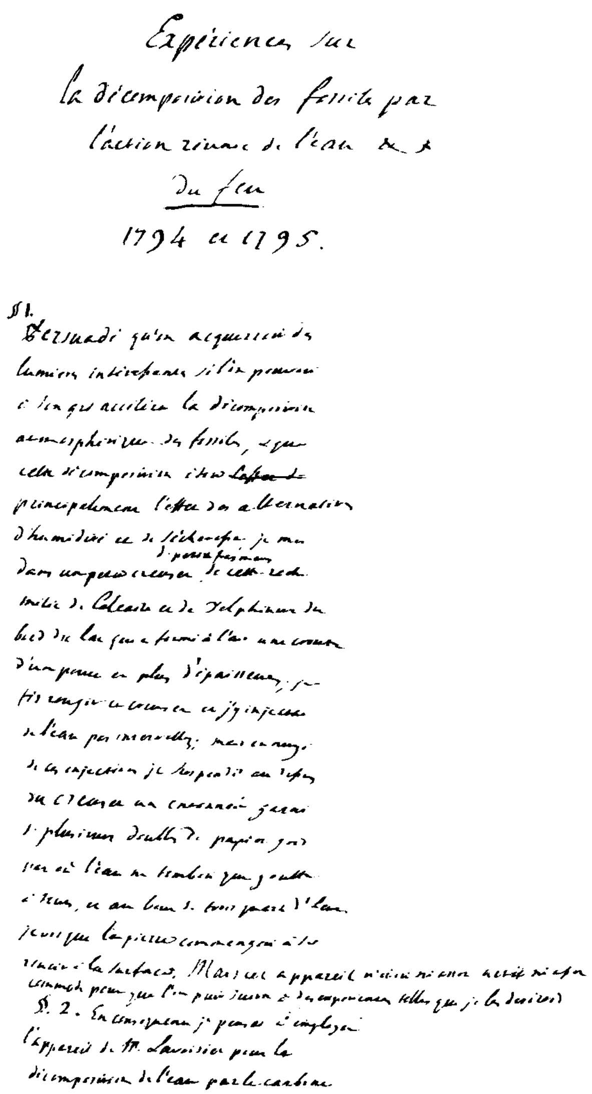

Figure 1. First page of Saussure's manuscript entitled "Expériences sur la décomposition des fossiles par l'action réunie de l'eau et du feu. 1794 and 1795." Archives H.-B. de Saussure, Public and University Library of Geneva, MS 82, fasc. 10. This illustration is presented to authenticate the manuscript and to show the modern reader a typical 18th-century scientific document whose deciphering is often difficult and time-consuming.

for ferruginous epidote) in a crucible. He collected the marble from the shores of Lake Geneva. In the natural state, in contact with the air, the delphinite crystals had developed a dark weathering crust an inch or more in thickness. He brought the crucible to a red color over burning coals and periodically sprinkled water on it. Not satisfied by the procedure, Saussure suspended a funnel containing several sheets of greasy paper over the crucible so that water would fall only drop-by-drop on the contents of the crucible. After 45 minutes, he noticed that the surfaces of the rock fragments were beginning to blacken. Although encouraged by these preliminary results, he felt that the experiment was not fast enough, did not allow comparisons, and was not sufficiently practical to undertake the studies he had in mind. Consequently, he devised three more elaborate types of experiments:

Type 1. Heating fragments of minerals or rocks in a dry state inside a crucible brought to a red color over burning coals and in contact with normal air ("air containing water vapor in a dry and elastic state").

Type 2. Heating fragments of minerals or rocks enclosed in a porcelain tube brought to a red color over burning coals and in which water was introduced continuously. The water source was from condensed water vapor in the beak of a retort in which water was boiled by another fire. This setup was adapted from an experiment A.-L. Lavoisier used for decomposing water by carbon and iron.

Type 3. Heating fragments of minerals or rocks in a crucible brought to a red color over burning coals and in which water was slowly introduced, one drop at a time, by means of a funnel containing sheets of greasy paper. The number of greasy papers (up to 12) inside the funnel regulated the rate at which water drops fell on the fragments of minerals or rocks inside the cru-

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cible. Another variation of this design was to introduce water via a sponge forced into the lower tube of the funnel. Both procedures, intended to simulate natural conditions of wetness and dryness, still did not perform to Saussure's satisfaction. Consequently, he inserted between the funnel and the crucible a small tantalum cup, which when almost full of water, emptied its contents rapidly by means of a siphon into the porcelain tube, with a periodicity of about 10 minutes. This setup worked well and simulated more realistically alternating conditions of wetting and drying of the rock and mineral samples.

Each of the experiments lasted about 4 hours and was repeated several times. In experiments 2 and 3, identical mineral or rock fragments were put inside a covered crucible which was brought to a red color on the same burning coals to allow better comparison of results.

Saussure used the following fresh minerals and rocks collected from Pleistocene to Recent alluvial deposits in the region of Geneva. He described them using the terminology of his time, without giving any justification for his choice, as follows:

Sample A. White jade with brilliant green smaragdite.

Sample B. Dark-green serpentine with light-green lamellar zones and darker veins.

Sample C. Shimmery and lamellar, white-grayish feldspar with minute black specks scattered over its surface (probably an orthoclase).

Sample D. Blue-greenish lamellar rock consisting of white quartz and light-green brilliant mica (probably a quartz chloritoschist).

SAUSSURE'S RESULTS AND MODERN COMMENTS

The results of Saussure's experiments are translated below and followed by my comments analyzing them in modern terms. The assumptions are based on the compilation of numerous papers describing the sequences of minerals developed from the natural and artificial weathering of jadeite, serpentine minerals, and orthoclase (for a complete review, see Nahon, 1991).

Sample A (jade)

Type 1 test. No visible changes.

Type 2 test. The jade became yellowish, the smaragdite developed a superficial and internal rusty color and showed a decrease in hardness. As a whole, the jade became more fragile by developing microfracturing.

Comments. The rusty color was due to iron oxidation which generated goethite, probably associated with smectite which was responsible for the observed microfracturing, because of its expansion and contraction associated with heating and quenching with water.

Type 3 test. The jade changed from yellowish to increasingly grayish, the smaragdite turned from rusty to grayish with loss of brilliance and further decreased in hardness.

Comments. It looks as if the formation of smectite became generalized and that a portion of the iron oxidized into goethite was probably incorporated within the smectite lattice, perhaps still as Fe^{3+} and not as the reduced form Fe^{2+}. Possibly, an iron-bearing smectite was formed (aluminous nontronite?). The generalized change to smectite accounts for the overall grayish color and the further general decrease in hardness.

The assumption of an initial generalized formation of smectite followed by more aluminous-ferriferous type is based on observations of the natural weathering of jadeite in ultrabasic rocks under lateritic conditions (see, for instance, Nahon *et al.*, 1982). Modern observations under SEM also reveal abundant microfracturing.

Sample B (serpentine)

Type 1 test. No visible changes.

Type 2 test. The groundmass of the serpentine acquired a light rusty yellow to gray-yellowish color, some of the lamellar zones remained light green whereas the veins became dark brown.

Comments. A portion of the iron of the serpentine oxidized into goethite. It appears as if the serpentine remained relatively unaffected and intimately mixed with the small amount of goethite generated. No traces of smectite are apparent.

Type 3 test. The groundmass of the serpentine became blackish-gray to blueish, the lamellar zones turned yellowish and became fragile, but the overall hardness remained unchanged.

Comments. Two possibilities should be considered. First, the serpentine was very iron-rich and altered to talc which incorporated the Fe^{+3} of the goethite, but because the general hardness remained unchanged, either a small amount of the serpentine altered or quartz was formed together with talc. Second, the serpentine contained originally a small amount of manganese which oxidized after the iron, leaving the final products talc and a dispersed manganese oxide (manganite?, birnessite?).

The assumption of the formation of talc is based on modern observations of the weathering of pyroxenes in ultrabasic rocks under humid tropical conditions (see, for instance, Noack *et al.*, 1986).

Sample C (feldspar)

Type 1 test. No visible changes.

Type 2 test. The feldspar developed a very thin crust, at least one line thick (the line was an 18th-century unit of thickness = 0.635 mm) of a dull yellow bistre color (blackish-brown), whereas the black specks at the surface became rusty yellow and increased in size at

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the expense of their surroundings. The interior of the crystal became whiter, fragile, and microfractured.

Comments. The surface of the feldspar was apparently rich in pyrite specks which oxidized into a thin goethite crust. The interior of the feldspar crystal changed into disordered alumino silicates, probably halloysite or metahalloysite, which always have a more whitish and more pearly aspect than kaolinite. Both products, because of their expansion and contraction associated with heating and quenching with water, were certainly responsible for the observed microfracturing.

Type 3 test. The external thin crust of a dull yellow bistre color appeared more altered and the whitish pearly interior of the feldspar crystal changed to a duller whitish color.

Comments. The surface of the feldspar appears enriched in goethite and the interior of the crystal changed to kaolinite. The assumption of the weathering of orthoclase to halloysite and then to kaolinite is based on a commonly-observed process (see, for instance, Parham, 1969; Berner and Holdren, 1979).

Sample D (quartz chloritoschist)

Type 1 test. Not undertaken.

Type 2 test. The rock developed a very thin crust about one line thick of a dull and light-brown color, a change which appears more related to the mica than to the quartz although the mica remained shiny.

Comments. In the 18th century, chlorite was called "green mica." It appears as if only chlorite underwent weak alteration into a small amount of clay (smectite?) and goethite. The fact that chlorite remained shiny indicates that only a small amount of alteration took place while quartz remained unaffected. Indeed, chlorite weathers as sheaves of sheets, explaining why they may take on yellowish colors and still appear as shiny blades.

Type 3 test. Not undertaken.

SAUSSURE'S CONCLUSIONS

On the basis of the above experimental results, Saussure concluded that dry heated air had no effect on rocks and minerals whereas water in the state of vapor or liquid was the active agent of weathering. Alternating periods of wetting by water and drying by heat were a far more effective process of weathering than heating in the presence of water. In his opinion, the experimental results confirmed his preconceived idea that natural weathering of rocks and minerals resulted from alternating, that is, seasonal periods of wetting and drying.

SUMMARY

Saussure's preconceived idea that weathering of minerals and rocks occurs by alternating, hence seasonal periods of drying and wetting, which he experimentally confirmed in 1794–95, is a remarkable foresight of modern ideas on the subject. This is particularly true in light of the modern understanding of the natural and experimental weathering of silicates (Nahon, 1991), namely that atmospheric heat has no effect on minerals and rocks because they were formed at much higher temperatures and that its only action is to increase the rate of weathering processes due to water in a vapor or liquid state.

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REFERENCES

Barry, R. G. (1978) H.-B. de Saussure: the first mountain meteorologist: *Am. Meteo. Soc. Bull.* **59,** 702–705.

Berner, R. A. and Holdren, G. R., Jr. (1979) Mechanism of feldspar weathering. II. Observations of feldspars from soils: *Geochim. Cosmochim. Acta* **43,** 1173–1186.

Carozzi, A. V. (1989) Forty years of thinking in front of the Alps: Saussure's (1796) unpublished theory of the earth: *Earth Sciences History* **8,** 123–140.

Freshfield, D. W. (1920) *The Life of Horace-Bénédict de Saussure:* Edward Arnold, London, 479 pp.

Nahon, D. B. (1991) *Introduction to the Petrology of Soils and Chemical Weathering*: Wiley, New York, 313 pp. See pp. 43–44, 75–79, 89–95.

Nahon, D. B., Colin, F., and Tardy, Y. (1982) Formation and distribution of Mg, Fe, Mn-smectites in the first stages of lateritic weathering of forsterite and tephroïte: *Clay Miner.* **17,** 1–9.

Noack, Y., Decarreau, A., and Manceau, A. (1986) Spectroscopic and oxygen isotopic evidence for low and high temperature origin of talc: *Bull. Minéral.* **109,** 253–263.

Parham, W. E. (1969) Formation of halloysite from feldspar: Low temperature artificial weathering versus natural weathering: *Clays & Clay Minerals* **17,** 13–22.

Saussure, H.-B. (1794–1795) *Expériences sur la décomposition des fossiles par l'action réunie de l'eau et du feu:* unpublished manuscript, Archives H.-B. de Saussure, Bibliothèque publique et universitaire de Genève, **82,** fasc. 10, 6 pp.

Saussure, H.-B. (1779–1796) *Voyages dans les Alpes, précédés d'un essai sur l'histoire naturelle des environs de Genève:* S. Fauche-Borel, Neuchâtel et Genève, 4 vols.

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