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A MANUSCRIPT OF HORACE-BÉNÉDICT DE SAUSSURE ON THE ORIGIN OF COAL: *ORATIO DE LITHANTRACE* (1770): SCIENCE, BUSINESS, AND ENVIRONMENTAL POLITICS

BY

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ABSTRACT

Until the end of the 18th century, the understanding of the origin of coal followed three distinct trends. First, peat and lignite, which clearly display the remains of wood and plant materials, were interpreted as representing former large expanses of forests, either buried in place or destroyed and transported by the waters of the sea during past catastrophes in the earth's history. In this approach, an implicit or explicit relationship with the Biblical Deluge was often implied.

Second, coal, which does not show any remains of vegetal material, was interpreted, often by the same authors who accepted the vegetal origin of peat, as inorganic material originating as liquid bitumen and rising as a consequence of subterranean fires. Bitumen was believed to be either injected in a pure state between layers of argillaceous sediments or shales, or more commonly to have impregnated these layers with preservation of their laminated texture. Thus was explained the banded texture observed in many coals.

The third approach was that lignite and coal shared the same origin, namely they were assumed to be accumulations of resinous wood transported from forests to the sea by former catastrophic processes. Lignite changed to coal with increasing depth of burial by a decomposition process involving only the original resinous matter of the tree themselves. The banded texture of coal was interpreted as similar to that of wood.

In his *Oratio de Lithantrace* (1770), a featured address at the commencement exercises of the Academy of Geneva, Saussure accepted the idea that coal was a shale impregnated by bituminous fluids. He presented an original structural interpretation of the Carboniferous coal basin of France and Belgium. He stressed the sedimentological and stratigraphic features of coal beds which indicated to him that these beds were originally marine shales belonging to repeated sequences of sandstones, shales and other types of rocks: an early awareness of the cyclicity of coal-bearing deposits.

In his investigation of the Chattian (Oligocene) freshwater molassic sandstones of Dardagny, near Geneva, Saussure faced the unusual geological conditions of intercalated beds of black lignite devoid of visible vegetal remains and thus appearing like coal, and of sandstones oozing heavy petroleum and showing thin layers of pitch-black jet (ozokerite) also simulating coal. This unusual combination of features appeared to him a typical demonstration that coal was a shale impregnated by bituminous fluids. It was not known then that the association of bitumen and coal was entirely fortuitous.

Assuming that the quality of coal increased with depth, an idea particularly favored by those who believed in rising bituminous fluids--because the deeper the shales the stronger the impregnation--Saussure eloquently promoted a deep mining venture of the coal of Dardagny which eventually did not materialize. Concerned with the threatening effects of excessive deforestation during his time resulting from the production of charcoal for industrial use, Saussure strongly favored exploitation of coal which

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was cheaper than wood. He misled his audience, however, professing that breathing sulfurous fumes from burning high-sulfur coal would be salutary and not harmful to their health.

Knowledge about the origin of coal advanced somewhat when Buffon stated in 1778 that all coals were vegetal remains deposited in marine conditions and intimately mixed with bitumen (which he interpreted as liquid vegetal oil or animal fat), and subsequently indurated by the mixture of acids. After field observations of Von Beroldingen and Jean-André Deluc in the peat swamps of Northern Germany (1778), the modern idea was reached that all types of coal are the products of peat having undergone different degrees of coalification.

RÉSUMÉ

Jusqu'à la fin du 18ème siècle, la compréhension de l'origine du charbon a évolué de trois manières différentes.

1. La tourbe et le lignite, qui montrent clairement des traces de bois et de plantes, ont été interprétés comme de grandes forêts enfouies sur place ou détruites et transportées par des invasions marines liées aux anciennes catastrophes du globe. Cette interprétation contenait souvent une relation implicite ou explicite avec le Déluge.

2. Le charbon qui est dépourvu de toutes traces végétales a été interprété, souvent par les mêmes auteurs qui acceptaient l'origine végétale de la tourbe et du lignite, comme un produit inorganique provenant de bitume liquide montant vers la surface sous l'effet des feux souterrains. Le bitume aurait été injecté à l'état pur entre des couches de sédiments argilleux ou des schistes, ou le plus souvent aurait imprégné ces derniers avec préservation de leur texture laminée. Ce processus était censé rendre compte de la texture rubanée de nombreux charbons.

3. Cette interprétation attribue au lignite et au charbon la même origine, à savoir une accumulation de bois résineux transportés depuis des forêts à la mer par des catastrophes anciennes. Le lignite change en charbon par enfouissement croissant à la suite d'un processus de décomposition qui concerne seulement les matières résineuses des arbres eux-mêmes. La texture rubanée du charbon est comparable à celle du bois.

Saussure, dans son *Oratio de Lithantrace* (1770), un discours présenté lors des promotions de l'Académie de Genève, accepte l'idée que le charbon est un schiste imprégné de bitume. Il présente une interprétation originale de la structure du bassin carbonifère franco-belge. Il développe ensuite en détail les caractères sédimentologiques et stratigraphiques des couches de charbon qui indiquent à son avis que ces couches étaient à l'origine des schistes marins appartenant à des successions répétées de grès, de schistes et d'autres types de roches: un concept précurseur de la cyclicité des couches à charbon.

Dans son étude des grès molassiques du Chattien (Oligocène) de Dardagny, près de Genève, Saussure fait face à des conditions géologiques inhabituelles: à savoir des intercalations de couches de lignite noir dépourvu de traces végétales et de ce fait apparaissant comme du charbon; des grès d'où suinte du pétrole lourd et qui montrent en plus de fines couches de jayet noir (ozokérite) ressemblant aussi à du charbon. Cette association inhabituelle lui semble une démonstration typique de l'idée que le charbon est un schiste imprégné de bitume. A l'époque on ne se rendait pas compte que l'association bitume-charbon était entièrement fortuite.

En admettant que la qualité du charbon augmente avec la profondeur, une idée fortement soutenue par ceux qui croyaient à la montée des fluides bitumineux--les schistes les plus profonds étant les plus fortement imprégnés--Saussure va promouvoir avec éloquence un project d'exploitation minière profonde du charbon de Dardagny qui cependant ne verra pas le jour. Concerné par les effects dévastateurs de la déforestation excessive de son temps qui résultait de la préparation du charbon de bois à usage industriel, Saussure a été très en faveur de l'exploitation du charbon, moins cher que le bois. Cependant, dans son ardent désir de convaincre, il n'a pas hésité à faire croire à ses auditeurs que la respiration des fumées toxiques provenant de la combustion de charbon riche en soufre n'était pas nocive mais en fait salutaire pour la santé.

Le problème de l'origine du charbon progresse un peu quand Buffon en 1778 écrit que tous les types de charbons sont des mélanges intimes de débris végétaux déposés en milieu marin, intimément mélangés à du bitume--interprété comme de l'huile liquide végétale ou de la graisse animale--et ensuite durcis par le mélange des acides. A la suite des travaux de terrain de Von Beroldingen et de Jean-André Deluc (1778) dans les marais du nord de l'Allemagne, l'idée moderne a été introduite que tous les types de charbon représentent divers degrés de carbonisation de la tourbe.

INTRODUCTION

From the unpublished works of Horace-Bénédict de Saussure (1740-1799), we are presenting here the original Latin text and an annotated translation into English of a manuscript entitled *Oratio de Lithantrace*, 1770 (Lecture on coal) preserved at the Public and University Library of Geneva. The translation is preceded by a review of the evolution of ideas on the origin of coal until 1770, and followed by a discussion of Saussure's contribution and of the subsequent evolution of these ideas until the modern concept was reached at the end of the 18th century.

But beforehand we shall give a short introduction on the subject matter to make it easier for the readers as well as the authors, because readers not familiar with the field might find it helpful to have some knowledge about coal, and the authors would not have to refer repeatedly to present knowledge.

DEFINITIONS AND TERMINOLOGY OF COAL DEPOSITS

Modern studies indicate that coal deposits derived from original peat layers which accumulated in poorly-drained areas covered by prolific plant growth in intermontane basins, coastal swamps, and deltaic complexes. Peat forms at times under cold climatic conditions, but more generally in humid temperate to equatorial climates. The types of deposits listed below correspond to increasing degrees of coalification, that is the complex biochemical and geochemical diagenetic process of the various types of vegetal materials. In an oversimplified manner, the various end products can be considered the results of compaction and geothermal gradient upon burial followed by tectonic deformation. Besides the well-known numerous heating and industrial uses of coal, synthetic gas and oil are manufactured from it on a large scale.

Peat: unconsolidated deposit of semicarbonized plant remains with high moisture content (at least 75%). This initial stage of the development of coal contains about 60% carbon and 30% oxygen (moisture-free); the structures of vegetal matter are clearly visible. When dried, peat burns freely.

Lignite: a brownish-black coal that has undergone shallow burial. Its calorific value is less than 8300 BTU/lb on a moist mineral-matter-free basis. It ranges from *brown lignite*, or *brown coal*, which closely resembles peat, to *black lignite*, or *dark lignite*, close to subbituminous coal. In both varieties, original vegetal materials are clearly visible.

Subbituminous coal: a black coal which is dense, hard, and distinguished from lignite by higher carbon and lower moisture contents. It produces between 8,300 and 13,000 BTU/lb on a moist mineral-matter-free basis. Subbituminous coal still weathers significantly and is subject to spontaneous combustion. Traces of original vegetal materials are either barely recognizable or invisible.

Bituminous coal: it is the most important of all coals. It contains more than 14% volatile matters and has a calorific value of more than 11,500 BTU/lb on a moist mineral-matter-free basis. It is dark brown to black and burns with a smoky flame. Original vegetal materials are no longer recognizable except under the microscope. Megascopically, bituminous coal is often banded and consists of the alternation of four major constituents, each one derived from particular vegetal components : vitrain, a shiny black material with a glassy black luster is really an organic jelly or fundamental substance produced by the complete decomposition of vegetal materials; clarain, a laminated glossy black material, is similar to vitrain but contains figured bodies, such as spores and other debris; durain, a black, dull, granular material, consists of figured bodies: spores, seeds, roots, ligneous tissues, etc., set in a small amount of fundamental substance; and fusain, a dull black, powdery material which recalls charcoal, consists mostly of ligneous materials.

Anthracite: it is the coal with the highest coalification rank, often due to metamorphism, in which fixed carbon content ranges from 92% to 98%, associated with the loss of almost all its water and volatiles. It is hard, black, with semi-metallic luster and semi-conchoidal fracture. It ignites with difficulty and burns with a short blue flame without smoke.

Coal basins, scattered throughout the world, result from continental drift which was responsible for putting given continents under favorable conditions for peat formation at certain times in the earth's history. In the Carboniferous, coal basins developed extensively from North America through Western Europe into China along the equatorial belt of Eurasia, as well as in Gondwana (Brazil, South Africa, India, and Antarctica) in colder temperatures around the southern ice cap. All Carboniferous coals are mainly bituminous coals, among which anthracite developed by metamorphism related to the orogenic deformation at the end of the Paleozoic.

Favorable conditions of peat formation developed again from Middle Jurassic through Cretaceous and into the Cenozoic. Extensive Jurassic coal deposits occur in China and Iran, and Late Cretaceous to Early Cenozoic coals in Western North America. Most of these coals are subbituminous or lignites, with a few bituminous ones; they were weakly folded by Cenozoic orogenic deformations. Lignite deposition continued in suitable environments scattered over most of the world during the Late Tertiary.

Today, peat is forming in high latitudes in areas of recent glaciation, but more abundantly in warm temperate and tropical regions (Florida, Mississippi delta, Amazon basin) where they provide an analog to ancient peat formation.

In this paper, the general designation of "coal" includes the modern terms of subbituminous coals, bituminous coals, and anthracite.

REVIEW OF THE CONTROVERSY ON THE ORIGIN OF COAL UNTIL SAUSSURE'S TIME (1770)

In a fully-documented study on the origin of coal, from which we have abstracted freely, K. A. Weithofer (1917) stressed the fact that from the Renaissance until the end of the 18th century, the understanding of the problem suffered from a long-lasting and misleading dual approach. Indeed, peat and lignite [brown coal, *Brownkohle*, *charbon de terre*]* which clearly display remains of wood and plant materials were described and interpreted differently from subbituminous and bituminous coals [*lithantrax*, *Steinkohle*, *charbon de pierre*] which, to the naked eye, showed mainly banding and no obvious traces of organic origin.

Upon recognition of the remains of tree trunks and plants in peat and lignite, the question was raised how they had been accumulated in layers inside the earth's crust. Opinions varied from plants and trunks uprooted from mountains or plains and accumulated by streams or marine waters, to forests invaded by the sea or destroyed in place by the Biblical Deluge. In fact, the Deluge, although not always explicitly mentioned, often played an important background role.

With respect to coal, a direct relationship between various types of bitumen and coal was assumed consistently with little variants from one author to the other. Indeed, since the earliest recorded history, the major types of bituminous materials such as petroleum (called napthta at the time) and asphalt had been widely known as natural seeps, burning fountains, and asphalt lakes. In the absence of clearly visible vegetal remains in coal, the conclusion was reached that coal was either pure bitumen indurated by some unknown process, or that it had become indurated by mixing with other mineral substances, such as clays, marls, or sulfur. Furthermore, distillation of coal in laboratory retorts released several types of flammable light and heavy oil which were assumed to be the best demonstration of its assumed bitumen origin.

It is important to realize that these two different interpretations were based essentially on the study of rocks as individual samples, or, at best, as single layers long before it was understood that peat, lignite, or coal were sedimentary deposits which implied a particular environment of deposition, a paleogeographic and paleoclimatic setting, a particular position within a stratigraphic sequence, and finally, burial processes and tectonic deformation explaining their geometrical attitudes.

Among the numerous authors who dealt with the origin of peat, lignite, and coal, some are discussed below as particularly representative of the above-mentioned dual approach, others because of unusually interesting ideas on the subject.

Georg Agricola (1546) described earthy coal (lignite) as a fossil earthy bitumen. In a long discussion he dealt disconcertingly with all types of flammable bituminous materials including liquid petroleum, asphalt, jet, and coal. Conrad Gesner (1565) included various types of so-called soft and hard coals under the heading of "*Bitumina*." Levinus Lemnius (1573) called coal unambiguously indurated bitumen. In his discussion of peat, he said that many Belgian authors believed it was made of destroyed trees and flooded forests, an unsupported opinion which they based solely on the occurrence of all kinds of vegetal matters, whereas he would rather compare peat to mineral veins or coal beds. According to Athanasius Kircher (1678), peat consisted of

* In the following review, the comments of the authors of this paper are placed within brackets.

wood which was softened by some kind of strong salt and then penetrated by earths whereas coal was bitumen mixed with sulfur.

Johann Philipp Bünting (1693) took an extreme medieval mineralogical-chemical yet deistic view, saying that coal did not consist of bitumen but was originally a mineral in its own right growing underground from its seeds like other minerals, which had been created by the grace of God for the benefit of humans living in regions devoid of forests. He assumed coal would continue to grow and propagate until the end of this world. Bünting however felt that the idea of coal beds being forests flooded by the Deluge and consisting of rotten tree trunks buried in the earth was ridiculous and childish. It showed that people who spread this idea had obviously seen but a few mines, and had not been underground to observe mineral deposits; therefore their reasonings had neither basis nor common sense. For Michael Bernhard Valentini (1704), coals or *anthraces* were a hard substance consisting of earth pitch and shale (*Schifferstein*) which in some way was a salt [compound] of petroleum molten and set in place by subterranean fires.

Antoine Jussieu wrote a memoir in 1718 on the traces of fossil plants observed in the black and gray shales overlying the coal beds of St. Chaumond in the Lyonnais, France [Carboniferous, Stephanian of St. Chamond, 7.5 miles east-northeast of St. Etienne]. After describing numerous imprints of "exotic" plants occurring between the shale laminae, which he compared to "the pages of the oldest library of the world," he attributed their origin to a transport by flotation by marine currents coming from the southern seas, namely either from the Eastern or the Western Indies. However, he considered the coal itself made essentially of indurated bituminous oil (p. 365) which had also impregnated the shales directly overlying the coal, changing their color to black. Coal layers which separated the shales containing plant imprints were bitumen, at first liquid, then infiltrated and subsequently indurated between layers with figured stones (p. 374).

Jussieu's concept of injection from depth of an original liquid bitumen between layers of marine shales can be contrasted with the assumption among early authors that oil impregnated a pre-existing layer of fine-grained earthy material, perhaps shale [Valentini, *op. cit.*, talked about *Schifferstein*]. Georg Anton Volkmann (1720) held that wood buried by the Deluge [lignite] was either petrified, fresh and unchanged, or rotten in a way that most of it resembled either half or entirely burned coal (p. 87). However, he said (p. 272) that coal (*Steinkohle*, *carbones fossiles*) was a mixture of earth, earth's pitch, sulfur, shale (*Schieferstein*) or petrified mud, including wood, forming a pitch-black hard substance.

Johann Jacob Scheuchzer (1723a), an ardent supporter of the Deluge, distinguished coal (*carbones fossiles*), which he considered indurated bitumen (*ex Bitumine sunt concreti*), from underground wood (*unterirdische Hölzer*), representing forests destroyed and flooded by the Deluge [he was describing Miocene (Tortonian) black lignites of the Tortonian (Miocene) upper freshwater molasse at Käpnach, near Horgen on the shores of Lake Zürich, see his *Meteorologia et Oryctographia Helvetica in*

Helvetiae Stoicheiographia..., 1716-1718, and *Itinera per Helvetiae...*,1723b. In both works he gave a short account of the chemical composition and rudimentary distillation of underground wood]. In a posthumous edition of Scheuchzer's *Natur-Geschichte...* (1746), it was his opinion that all kinds of fruits, seeds, snails, and bivalves as well as grasses whose shape resembles those existing today--as one egg resembles another--were randomly mixed with lignites [very often they occur in the overlying claystones as well, see Heim, 1919, p. 84]. Therefore, Scheuchzer concluded that coals (*Steinkohlen*) were a mixture of sulfur, mountain sap, earth's pitch, and rock rather than rotten wood buried by the Deluge. Furthermore, the amount, position, and location of these coals indicated that they could not have been wood.

Johann Hartmann Degner (1729, 1760), in a remarkable work on the origin of peat whose vegetal origin he understood perfectly, was of the opinion that coal was an indurated mineral pitch. Johann Gottlob Krüger (1741?, 1746), wrote a short paper on coals, considering them as a mixture of stone or shale with earth pitch, naphta, mineral oil or petroleum, and real sulfur. He attempted to demonstrate that coals were different from the so-called "immature coals" [lignite] which consisted of real wood buried underground by a former flooding of the region of Halle where his investigation was made. With respect to the origin of shales associated with coal and originating from a wet earth (*sumpfige Erde*), he assumed a general flooding of the earth. This wet earth lost its water through the action of subterranean heat which also formed petroleum, whose origin belonged unquestionably to the mineral kingdom.

The contribution of Johann Gottschalk Wallerius (1750, 1759) was of crucial importance in the light of the great reputation of the Swedish mineralogist. He classified coal under the heading of "*Bitumen lapide fissili mineralisatum, Lithantrax, Fissilis bituminosus*." According to him, coal submitted to complete distillation released the following: 1. an alcohol; 2. acid sulfurous vapors; 3. light oil resembling naphta; 4. heavier petroleum oil which flowed at the bottom of the previous one and sublimated under strong fire; 5. an acid salt like the one from amber; 6. black pure earth which remained in the retort, was not flammable, and released no smoke. Wallerius concluded that coal consisted of naphta or petroleum oil which had penetrated a wet earth (*Sumpferde*) or marl (*mergelartige Erde*) and which had indurated in beds or layers, and changed to fossil coal after some transient sulfurous vapor became mixed with it.

This was the first clear statement that coal was a wet argillaceous sediment impregnated by liquid bitumen that subsequently indurated. Of importance, along this line of thinking, was the opinion of Christian Friedrich Schulze (1759) who stated that coal was a pitch-like mineral originating from oil (*Erdöhle*), which penetrated the layers of shale beds and filled them. He distinguished three final products of this process: pitch-like and hard coal, shaly coal, and "dead" coal (*taube oder todte Steinkohle*). Furthermore, with respect to shale beds overlying the coal, he said that because of the appropriate degree of cohesion of their constituents, they were responsible for the concentration in the underlying shales of the oily vapors rising from the depths of the earth.

Johann Gottlob Lehmann, a diluvialist by opportunism, dedicated in his description of the strata in Thuringia (1756) a section to the flammable minerals he observed (p. 206-209), including coal (*Steinkohle*) occurring in layers which can be either real coal (*Steinkohle*) or the so-called brown wood or earthy coal (*Holzkohle*, *Erdkohle*). He was apparently the first to introduce the term *Braune Holzkohlen* into the German language. Lehmann felt that the reason why these flammable substances occurred so commonly and so abundantly in Flötz layers was because they contained a great amount of vitriolic acid which, when combining with fat earth, always generated sulfur. But, he added that all this belonged really to chemistry. He also mentioned that peat, which occurred always in horizontal layers, also belonged to the flammable substances, although originally from vegetal material, because it contained a small amount of sulfur and earth pitch. [Lehmann described in fact the coals intercalated at the base of the Autunian (Permian) of Thuringia because he said that they always occurred at the base of the *Flötz-Schichten* overlying the *Gang-Gebürge*. These coals are indeed lignites in which he must have recognized wood structures as well as subbituminous coals devoid of them.] In the same work (p.231-233), Lehmann mentioned that imprints of plants and flowers occurred in shale beds accompanying the coal, an observation, he felt, which further demonstrated his idea that coal beds were the first Flötz layers, and that plants uprooted and floated from mountains and plains [by the Deluge] were associated with the wood forming the coal, because, having been enclosed within the beds of clay, they left their imprints in these beds after their original substance decayed. He also stated (p.231) that the occurrence of entire tree trunks in the depth of the earth could be understood only if the process he assumed [the Deluge] was taken into account.

Paul Henry Thiry Baron d'Holbach wrote two articles on the origin of coal in volume 3 (1753) of the *Encyclopédie ou Dictionnaire Raisonné...* entitled respectively "*Charbon minéral*" and "*Charbon végétal et fossile*", both articles ending with the sign (-) identifying the author. He stated that two types of mineral coal were generally distinguished. The first one is hard, compact and has a shiny fracture surface. It is difficult to ignite but once burning gives a clear and shiny flame accompanied by thick smoke. This best type is called "*charbon de pierre*" [coal] and generally lies deeply buried; it contains a much higher proportion of bitumen than the second type. The latter is friable, soft, and decomposes upon contact with the air. It lights rather easily, but gives a short-lived flame. It is called "*charbon de terre*" [lignite] and occurs nearer to the surface of the earth where it is mixed with extraneous materials. Its location indicates that it lost most of the lighter fraction of bitumen it originally contained.

D'Holbach then proposed his own ideas, namely that coal is of vegetal origin and was formed during the revolutions which occurred on our globe during the remotest times. Entire forests of resinous trees were engulfed in the earth where, in the course of many centuries, the wood underwent decomposition which increased with depth. This is shown by *charbons de terre* [lignites] being underlaid at depth by *charbons de pierre* [coal]. Through this process, wood changed into clay or stone which was penetrated by the resinous matter contained in the trees themselves before decomposition [this is

MÉMOIRE

SUR

L'UTILITÉ, LA NATURE ET L'EXPLOITATION

DU

CHARBON MINÉRAL;

Par M. DE *TILLY.*

A PARIS,

Chez AUGUSTIN-MARTIN LOTTIN, l'Aîné,
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FIG. 1.

Title page of de Tilly's memoir on coal (1758). Rare Book Room, Library of the University of Illinois at Urbana-Champaign.

obviously a new approach which implies that lignite and coal shared the same origin, namely accumulations of resinous wood transported from forests to the sea by former catastrophic events. Lignite changed to coal with increasing depth of burial through a decomposition process involving only the resinous matters of the trees themselves, with no addition of any other substances, such as petroleum, bitumen, or sulfur as previously assumed]. D'Holbach said that this process was proved by the fact that a texture similar to that of wood could be observed in the sheets and laminae forming the coal, and that overlying shales contained many plant imprints [quoting Jussieu, 1718, *op. cit.*].

In the extensive footnotes of his translation of Lehmann's work (1759), d'Holbach repeated his interpretation of coal, adding that distillation of coal generated the same products as that of the resin of trees. He stressed that to understand how a great amount of wood could have been transported inside the earth, one should recall Charles-Marie de la Condamine's observations in his *Voyages dans l'intérieur de l'Amérique méridionale...* (1745) that the Amazon River carried huge amounts of trees, even entire forests, which were transported to the sea. [One of the authors of this paper (AVC) has seen several floating islands in the Amazon, where the erosion of this huge meandering river undermines its margins, setting free large fragments of the bordering jungle with their intertwined roots and mangrove clumps. These floating islands which may be large enough to support fishermen huts, on their way downstream may occasionally become attached again, temporarily or permanently, to the banks of the river, confusing even the professional pilots who take ocean-going ships from the Amazon delta up to Manaus. Floating islands, before total disintegration, may often drift far at sea into ship lanes and become temporary navigational hazards.] Johann Georg Gmelin in his *Reisen durch Sibirien...*(1751-1752) had also observed that the sea carried incredible amounts of tree trunks which accumulated along its shores where they eventually built some kinds of mountains.

The often quoted book by de Tilly (1758) is only a review of previous opinions ranging from Scheuchzer to Wallerius and to the *Encyclopédie* (Fig. 1); the same applies to the work of Antonio Zanon (1767). More interesting is the contribution of Carl August Scheidt (1763) who used the term of *bräunliche Steinkohle* as a synonym for *Holzsteinkohle* (p. 186) and interpreted them as the remains of rotten wood which through time was penetrated by petroleum and mixed with it. According to Scheidt, this material looked at depth like indurated flowing pitch in which the tree rings could no longer be seen, whereas at the surface it was brittle as wood sunken in water [this description obviously applied to lignites]. With respect to coal, he said (p. 174) that according to chemists, it was a mixture of watery vapor, acrid smelling sulfurous vapor, two kinds of earth oils, an acid salt, and a loose wet earth (*Sumpferde*).

In 1763, Elie Bertrand published his *Dictionnaire universel des fossiles propres et des fossiles accidentels...*which contains a section on *Charbon fossile, ou charbon de terre, ou charbon de pierre, lithantrax, et houille.* After a review of previous contradictory opinions, he stated that in order to avoid confusion, the designation of fossil coal should be restricted to materials in which the plant or vegetal origin is obvious, and the designation lithantrax to the black schistose or fissile substances.

Bertrand thought that it was an error to think that coal [*charbon de pierre, charbon minéral*] was decomposed wood changed to silt (*limon*) and impregnated by petroleum, bitumen, vitriolic acid, and sulfur as stated in the *Encyclopédie*, vol.3, 1753. In his opinion, coals [*lithantrax*] were layers of silty, argillaceous, and marly materials which were variably penetrated by *moufettes* [subterranean gases], sulfurous vapors, and bituminous or petroliferous juices [fluids]. Some of these beds were extremely old, others originated from the Deluge as shown by imprints of plants and insects which occurred sometimes within the beds overlying coals as shown by Jussieu [1718, *op. cit.*, although the latter was not a believer in the Deluge as seen above].

Bertrand refuted the idea that coals were accumulations of floated woods [a reference to d'Holbach, 1759] asking how beds of coal reaching 40 to 45 feet in thickness and extending over several leagues could be visualized as decomposed trees. He said that certain beds of coal, only a few inches thick, were extremely widespread; how could they represent a buried forest or destroyed trees ? Bertrand also observed superposed coal beds separated by intervening layers of rock, earth, and gravel. How could these beds represent forests which had grown one on top of the other ? Finally, he stated that if certain coal beds did have a ligneous or fibrous texture, others showed the very bed of silt and marl which was changed into coal so that one portion of the bed was coal and the rest still earthy and marly.

In summary, until the presentation in 1770 of Saussure's *Oratio de Lithantrace*, the following two general concepts had been presented:

1. Peat and lignite were believed to be of vegetal origin, resulting from huge expanses of forests buried in place or destroyed and transported by the waters of the sea during past catastrophes in the earth's history. An implicit or explicit link to the Biblical Deluge was often present.

2. Coal was interpreted, often by the same authors who accepted the vegetal origin of peat and lignite, as inorganic material, originating as liquid bitumen and rising as a result of subterranean fires. It was thought to be injected in a pure state between layers of wet argillaceous sediments or impregnating shales with preservation of their laminated texture, thus explaining the banded texture of many coals. Both variants of the process were followed by some kind of induration. Other authors considered coal as inorganic, but felt it was a complex mixture of rock or shale, earth pitch, mountain sap, petroleum, naphta, sulfur, with or without pieces of wood, a mixture which turned black by the action of subterranean fires.

3. D'Holbach is to be singled out from the above-mentioned dual approach. He interpreted coal as the accumulation product of destroyed forests in which wood underwent decomposition, increasing in intensity with burial, and changed into clay or stone which were penetrated by the resinous matter. This matter originated from the trees themselves without any addition of extraneous materials.

ORIGINAL LATIN TEXT OF *ORATIO DE LITHANTRACE*

Notes on Sources

The literary form is a dialog consisting of a question from a well-coached student in philosophy which provides the opportunity for his professor for a long reply (oration) based on his experience and his recently completed trip to Great Britain in 1768. A similar dialogic form, presented as a class discussion, was used by Saussure in his discussion on mountain building entitled *De Montium Origine*, 1774 previously analyzed (Carozzi and Newman, 1990). *Oratio de Lithantrace* was read by Saussure in June 1770 as the featured speaker at the Commencement Exercises (*Promotions Académiques*) of the Academy in the Temple, that is St. Peter's Cathedral of Geneva (See reference in *Voyages dans les Alpes...*, 1779, vol. I, footnote to § 64). The choice of the young professor, age thirty, can be seen in the light of the fact that since 1766 he had been Secretary of the Venerable Company of Pastors which, among other duties, practically controlled the Academy of which he was to become Rector in 1774. In his address, Saussure took advantage of the presence in the audience of all the civilian and religious leaders of Geneva, to combine skillfully science with business and environmental politics. He concluded his scientific discussion by calling upon the local authorities to invest funds and promote the search and exploitation of the assumed commercial coal deposits in the vicinity of Geneva, and by summarily dismissing the effects of obnoxious fumes that the industrial use of these low-ranking coals might release.

Oratio de Lithantrace as manuscript exists in two versions. The first one, dated 1769, is a well-organized but heavily corrected first draft in Saussure's own handwriting of 22 pages, half of them deleted (Saussure, 1769). The value of this first draft is that it contains the list of the major authors he consulted for his discussion: Ulisse Aldrovandi (1701); Scheuchzer (1723); *Encyclopédie* (1753); de Tilly (1758); Lehmann (French translation by d'Holbach, 1759); Bertrand (1763); and the famous physician Hoffmann (1695, 1736, 1754).

The second version, dated 1770, and written by an unknown copyist, is the text of the address which corresponds exactly to the undeleted portion of the first draft but contains only the names of the naturalists he quoted (Saussure, 1770).

Notes on Style

The Oration is written in "academic" Latin, with the use of many abstract nouns and *quod* clauses of indirect speech which the classical purist would avoid, and with some un-classical vocabulary (*vicinia*, *autumem*), but all the same with great art.

It opens with a certain domestic humor, as the ladies of Geneva are heard complaining about the expense of buying wood. Every husband in the audience was familiar with the "timely complaints" with which his wife had urged him to do various chores from which he was hoping to be excused! But the speaker gracefully extricates himself from the appearance of being ungallant by eventually giving best to the ladies after all.

The young professor maintains an air of modesty (*captatio benevolentiae*). He wishes at the outset that he were able to do justice to his theme, and at the end will be satisfied if his "brief address" lends even modified support to his proposal.

As in *De Montium Origine*, a picturesque passage occurs about halfway through, obviously calculated to combat by *varietas* any boredom which the technicalities of his lecture may rouse in the unscientifically inclined portion of his audience. It presents the speaker as in some personal discomfort, if not danger, as a result of his intrepid investigations in the collieries of the north of England. The picture is enhanced by the *chiaroscuro* of *tenebrosa tenuium candelarum lumine*, worthy of Georges La Tour (1593–1652).

The miners are seen here indeed more by the eye of the artist than the mind of the scientist. The deadly fire-damp, for example (*moufette*), is allegedly easily dealt with by the opening of ventilation shafts. But an English historian (Johnson, 1991, p. 541) notes that fire-damp deaths were recurrent, and there is no mention at all of the danger of appalling accidents such as that which occurred—of course long after Saussure's visit—at Felling Pit, near Sunderland, on May 25, 1812, in which 92 men and boys died, and which led Sir Humphry Davy to design the safety lamp.

Similarly, although some of the dreadful exploitation of female and child labor later prohibited by Act of Parliament must have been visible when de Saussure went down the mines, he attributes the pumping of water to cleverly designed steam engines. But children were described as doing this sort of work and standing 12 hours a day in water in the First Report of the Children's Employment Commission as late as 1842.

The miners and their families in reality lived above ground in poor and even squalid conditions. But in the Oration they are seen in some cases at least as living perpetually underground (which would of course have been extremely unhealthy, especially for babies and children) as part of a romantic traveller's tale. It is true that the pit ponies used to pull the wagons were never brought to the surface. Has Saussure confused a story about them with a story about the human workers? He also claims on the evidence of the German physician Hoffmann that coal fumes are good for the health, and that London's problems are due to its low-lying site along the Thames. Is there possibly some tinkering with the facts in all this in order to dampen opposition to the proposal to open a Genevan mine? In that case, the author's elegant Latin rhetoric would be employed in a less than worthy cause.

In another colorful passage, we see the energetic young scientist in the forests of Dardagny, accompanied by the Sieur de Dardagny's warden, testing the ground with his hoe and listening to stories about oil deposits from the local inhabitants.

To turn to stylistics, some of the Latin is excellent even by stringent Classical standards, and attests Saussure's close reading of the authors. Idioms such as *quam sententiam lubens amplector, cum nostra tam liquido conspirant, ut iis immorari omnino superfluum esset, nullus haereo quin .... , nisi edicto futuris iurgiis occurreretur*, would do credit to the modern specialist in Latin prose. Elsewhere, the author knows words like *consectaria* and *ansa*, and has no trouble in rendering into Latin expressions describing the screws used to raise the coal up the shafts or the steam engines designed to pump water out.

There is also a discernible rhetorical structure. Some of this we may attribute to de Saussure's own ear. Cicero's fondness for the clausula ending of resolved cretic + spondee is already mocked by Tacitus (*Dialogus* §23), but we find a number of such rhythms in the Oration. Often they are secured by the different forms in which *reperio* is placed at the end. So, for example, *Lithanthrace reperiri*, *Lithanthraces reperiuntur*, *profundioribus reperiatur*, *fodinis reperiatur*. But this is not always the case. We also find: *esse referendam*, *pertractanda revocaret*, *saeviente patiantur*, *esse tribuendos*.

Roman taste eagerly embraced even in prose rhyme and syllabic balance. Saussure shares this sympathy. A striking example of parisosis and homoeoteleuton is found for example in a passage where he is refuting the vegetable origin of coal by evoking the majestic processes of Nature. This brings out the poetry in the professor:

per strata accurate sibi invicem incumb**entia**	17 syllables
totamque venarum latitudinem occup**antia**	16 syllables
non silvas ruinosa subversione sepultas	15 syllables
arboresque confuse cumulatas reprae**sentat**	15 syllables
sed lente, diu uniformiter et ordinate agentis naturae **signat**.	27 syllables

In this last clause, although it counts only 27 syllables on the page, we may imagine that the slow pace of weighty delivery, as the speaker emphasized with the aid of four adverbs the enormity of geological time, easily added another three syllables' duration. In this sense, it is proper to talk of Saussure's artistry as essentially oral.

And again:

Quae liquida bitumina ubi ad telluris superficiem prode**unt**,	22 syllables
et aquas ex collibus effluentes rubiginoso colore ting**unt**	21 syllables
optimum indagatoribus Lithanthracis indicium praebent	19 syllables
illi terebra terram explor**ant**,	10 syllables
et si alia prospera auspicia inveni**ant**,	16 syllables
perpendicularem puteum sine mora excav**ant**	16 syllables

In several places, the speaker reveals himself as an ardent patriot. By using the Greek noun *dynasta* (δυνάστης) to describe the Sieur de Dardagny and *dynastia* (δυναστεία) for his estate, he establishes the implicit comparison between Geneva and Greece which we also noted in *De Montium Origine*. But patriotism is nowhere clearer than towards the end of the Oration, in the appeal to the Dignitaries of Geneva, where a whole paragraph (*quis autem dubitat ... incitentur?*) is made up of a single complex sentence, containing five relative clauses introduced by *qui*. Here, the full *gravitas* of the Classical manner is employed to make the point. At the very end, in the final sentences of all (*Ipse contentus ... Dixi*), we find consecutive clauses of 8, 8, 17 and 16 syllables.

The Oration as a whole is a fine example of humane letters drawn from a now departed era, in which a sensitive, poetic style and vigorous argument are joined with acute scientific observation and shrewd economic calculation.

Quaestio

Cum pleraeque montanae regiones ligno abundent, nostraque Patria medios inter montes sita sit, saepe miratus sum Matresfamilias de ligni caritate queri; atque initio pronus eram ad censendum tales querelas ex aliqua morositate, aut nimia parsimoniae cupiditate oriri. Verum ubi a peritissimis Oeconomis accepi revera ligni pretium quotannis extra modum augeri, immo et metum esse ne prava administratio qua fit ut in Sabaudia silvae promiscue et ante iustam maturitatem secentur et eradicentur, ad intolerabile pretium deferret mercem domesticis usibus et opificiis adeo necessariam, tunc me in Matresfamilias iniuriosum fuisse, easque tempestivis querelis viros ad remedia invenienda excitare sensi. Qua occasione saepius etiam audiebam celebrari felicitatem earum regionum quae Lithanthrace seu Carbone fossili abundant, cum ex eo bituminis genere, non modo focis nostris alimentum, sed et etiam officinis opificum exiguo sumptu ignes suppeditentur. Quae curiositatem, simul et novae adipiscendae utilitatis curam animo excitaverunt. Ab eo scilicet tempore valde aveo scire, quid sit ille Carbo fossilis, undenam originem suam ducat, et qua ratione tam immensae illius massae potuerint in terrae visceribus coacervari; atque cum tale bonum patriae nostrae denegatum fuisse aegre feram, scire studeo, an non sit aliqua spes Lithanthracis venas in Urbis nostra vicinia reperiundi, sicque magis in dies metuendae lignorum inopiae medendi.

Cum autem sciam te, Professor Clarissime, nuper in Anglia Lithanthracis feracissima regione commoratum fuisse, atque autumem, te Naturae studio intentum, rem curiositate et attentione adeo dignam non neglexisse, quaestiones meas omni Genevensi momentosas, tibi in hoc solemni Eruditorum conventu proponere nequaquam dubito.

Oratio

Quas proponis quaestiones, Ornatissime Adolescens, ad Historiam Naturalem et Oeconomiam simul pertinentes dignae sunt certe quae nobilissimi huius coetus contemplationi offerantur. Utinamque iis ex merito tractandis et elucidandis idoneus essem! Verum, quae legendo, observando et meditando didicerim paucis, ut potero, exponam.

Lithanthrax seu carbo fossilis ex Graeco λίθος lapis et ἄνθραξ carbo corpus est fossile de genere bituminum nigrum tenaxque, quod inter ignis alimenta fortius et diutius ardorem servat. Varia sunt eius genera pro duritie et puritatis gradu. Varias ad altitudines sub terra deprehenditur: quibusdam scilicet in locis Lithanthracis venae ad ipsam telluris superficiem adscendunt; alibi ad centum et amplius hexapedas demerguntur. Pleraeque venae ab oriente in occidentem procurrunt versus meridiem inclinatae. Magnum saepe telluris tractum traiciunt descendendo primum seque in profundiora immergendo usque ad certam distantiam certamque altitudinem, ubi horizontales fiunt, iisque in locis quae *plateur* a Gallis fossoribus vocantur ditissimae sunt et melioris notae carbonem suppeditant; sed exinde mox adscendentes telluris superficiem repetunt.

Quanam autem ratione in telluris visceribus formatum est illud bitumen, quanamque causa sic ordinatum?

Maxima pars Recentiorum eius originem a vegetantibus deducens contendit immensos silvarum tractus magnis quas tellus passa est vicissitudinibus sepultos fuisse et longa in subterraneis mora in carbonariam substantiam degenerasse. Nec sane argumentis maximam veri speciem isti opinioni conciliantibus destituuntur. Saepe enim supra Lithanthracum strata et in eorum vicinitate certissima reperiuntur plantarum vestigia et quidem talium plantarum quae in silvis potissimum crescunt. Praeterea Lithanthracis contextus ligni texturam ita nonnumquam aemulatur, ut fossiles aliqui carbones a lignariis carbonibus aegre primo aspectu secernantur. Porro vera et indubitata ligni frusta nec non integrae arbores repertae sunt quae totae in Lithanthracem mutatae videbantur. Nec desunt observationes lignorum sepultorum quarum suprema superficies veram ligni naturam et speciem retinuerat, inferior lignum quasi resolutum, infima verum Lithanthracem exhibebat.

Ista argumenta firmissima atque etiam inexpugnabilia mihi videbantur, donec Lithanthracis fodinas ingressus omnia oculis lustrando dubia primum, mox eadem fluxa et facilem contrariae opinioni viam concedentia deprehendi.

Quid igitur? Primo didici Lithanthracem saepe saepius absque ullis plantarum vestigiis et vice versa plantarum vestigia saepius absque Lithanthrace reperiri. Dein ubi carbonis fossilis substantiam oculis admovi, vidi quidem in ea distingui posse strata quae ligni fibras laminasque mentirentur, sed quae in tegula etiam, *l'ardoise*, gypso, innumerisque fossilibus originem suam a ligno nequaquam deducentibus possent observari. Praetereaque ipsa illa regularis constansque dispositio per strata accurate sibi invicem incumbentia, totamque venarum latitudinem occupantia, non silvas ruinosa subversione sepultas arboresque confuse cumulatas repraesentat, sed lente, diu, uniformiter et ordinate agentis Naturae vestigia signat. Et si nonnumquam reperiantur ligna verum in Lithanthracem mutata, ne credas, Ornatissime Adolescens, eo ipso evinci omnes Lithanthraces ex ligno oriri: porosa enim et penetrabilis ligni textura facile fossilibus oleis imbui sicque Lithanthracis speciem acquirere potuit; pari ratione ac idem lignum in marmor atque etiam in marmore duriorem achatam, nec non in metallicam formam quotidie mutatum videmus, cum tamen nemo arbitretur marmor, achatam, metalla a lignis mutatis originem suam repetere.

Neque melius cum ista hypothesi consentiunt natura et dispositio venarum in quibus Lithanthraces reperiuntur. Venae enim nonnumquam directione fere verticali intra terram descendunt, sicque ad immensas saltemque incognitas altitudines demerguntur, cum tamen earumdem latitudo et crassities nequaquam tantae altitudini respondeant. Saepe enim vena licet late horizontaliter patens tam tenuis est ut lineam vix superet, et sub illa tenui expansione suppositis variis lapidum, harenarum, argillarumque stratis aliae procurrunt venae sibi invicem parallelae quae rupes interdum durissimas pervadunt. Quaero autem, qua ratione ea omnia phaenomena, quae non semel aut bis fortuito contigere, sed quae in omnibus Lithanthracum fodinis possunt observari, cum sepultis silvarum tractibus conciliari queant? Ipsa etiam chemica

Lithanthracis analysis si accurate instituatur vegetabili eius origini prorsus contradicit. Ex Lithanthrace enim sicuti e sucino omnibusque aliis fossilibus oleosis extrahitur singulare genus salis acidi sicci, quod numquam ex ullo quocumque vegetabili extractum est: cineresque quos combustus Lithanthrax relinquit vegetantium cineribus prorsus dissimiles sunt.

Istud igitur systema veluti caducum considerans ad aliud probabilius transeo.

Dixit Wallerius cuius sententia in talibus argumentis maximi ponderis est, carbonem fossilem nihil esse praeter limum vel margam phlogisto seu materia inflammabili saturatam. Quam sententiam lubens amplector, nisi quod non limum vel margam, sed potius argillam pro Lithanthracis basi agnoscendam esse censeo. Cuius sententiae fundamenta adstruere propero.

Modus quo Lithanthrax in venis suis per strata disponitur prorsus similis est rationi qua argilla ipsa in suis venis ordinatur. Carbo fossilis ad instar argillae exsiccatae in foliola sibi parallela dividitur. Idem semper in argillae vicinia reperitur, ita ut id genus terrae et lapides ipsi affines Lithanthracis indagatoribus optimum indicium suppeditent. Stratum ipsum lapideum carboni immediate superincumbens fere semper est genus aliquod tegulae, *d'ardoise*; tegulam autem ex argilla originem suam ducere neminem in fossilibus versatum latet. Praeterea saepe saepius in Lithanthracis fodinarum vicinitate occurrunt argillae, quae oleoso principio imperfecte saturatae imperfectum etiam carbonem exhibent; ut totius negotii arcanum quasi evulgatum deprehendere fas sit. Interea Lithanthracis cineres, quos vegetabilium cineribus adeo dissimiles dicebamus eius argillosam originem omnino demonstrant; quippe accuratae analysi subiecti vix quidquam praeter genuinam argillam praebent. Multae etiam observationes declarant Lithanthracem vel saltem eius matricem depositam fuisse simul cum reliquis telluris stratis in universalibus globo inductis mutationibus, cum saepe Lithanthraces reperiantur inter strata marinis exuviis referta constansque venarum ab Oriente in Occidentem directio similis directioni montium in nostro Continente clare ostendat, illam matricem eadem universali causa cum montibus formatam, <i>deoque ad maris sedimenta potius quam ad vegetantia esse referendam. Cetera phaenomena formam, situm, crassitiem venarum spectantia priori hypothesi adeo contraria cum nostra tam liquido conspirant, ut iis immorari omnino superfluum esset.

Quanam autem ratione iungitur oleum fossile cum argilla, ut inde nascatur Lithanthrax? Continuas esse in imis terrae penetralibus caloris causas, nec thermae tot in locis existentes nec vulcanii montes nec terrae motus nos dubitare sinunt. Unde autem ille calor? Ignem centralem alii, alii fermentationem adlegant. Systema centralis ignis iam a pluribus saeculis alternis fere vicibus admissum et reiectum nuper in novissimis Academiae Parisiensis commentariis novis speciosisque argumentis non tamen omni exceptione maioribus a Clarissimo de Mairan defensum est. Atque iamdudum assidui fodinarum operarii telluris centro viciniores fervidosque immo et igneos vapores ex earum fundo continuo prodire videntes de centralis ignis existentia nunquam dubitavere. Sed si, sepositis systematibus, admittas, Ornatissime Adolescens, quod est sine controversia, dari scilicet quam plurimis in locis subterraneas caloris causas, facile concipies, subtiles oleososque vapores ex terrae visceribus per rimas et cavernas sensim adsurgere, iisque corporibus adhaerere quae ipsos retinere possunt, argillis praesertim, quae ex detergendi facultate pro pinguedinis absorbentibus cognoscuntur. Nec minus intelleges cur maxima quantitas Lithanthracis optimae etiam notae in profundioribus reperiatur; huc scilicet primum ex intimioribus terrae appellunt vapores, nec ad superiora, nisi inferioribus iam saturatis perveniunt. Huius hypothesis consectaria tecum lubens persequerer, nisi tempus me ad alia necessaria pertractanda revocaret. Unicam superaddam observationem nostrae hypothesi mire faventem. Dantur in Italia montes bitumina inaequaliter crassa densaque fundentes, eo ordine, ut spississimum ipsae montis radices aegre evomant, fluidius ex iugis intermediis defluat, subtilissimumque naphtae nomine a veteribus decantatum ex montis cacumine exsudet; quae distillationem arte factam adeo accurate aemulantur, ut montis cavernae alembici, ignes subterranei ardentis furni vicem sustinere dici possint.

Quae liquida bitumina ubi ad telluris superficiem prodeunt, et aquas ex collibus effluentes rubiginoso colore tingunt optimum indagatoribus Lithanthracis indicium praebent: illi terebra terram explorant, et si alia prospera auspicia inveniant, perpendicularem puteum sine mora excavant, quem asseribus ligneisque ramis adversus terrarum lapsum munitum fodere non cessant, donec ad bonam divitemque Lithanthracis venam pervenerint, eoque utuntur ad descensum et carbonis extractionem. Saepius in tales puteos Eboracensis Comitatus descendi, calatho impositus et corpore ad funem calathum demittentem revincto; quae descensus ratio id habet incommodi, quod calathus libere in puteo oscillans alternis vicibus parietibus eius oppositis illidatur; interdum alterum parietem radens, si propter asperitates adhaeserit mox praeceps terrefactum viatorem ad medullam usque conquassat. Sic tamen ad venam quinquaginta et plures hexapedas profundam salvus perveniebam, et post incommodam satis et diuturnam reptationem secundum venam evacuatam ad operarios veniebam, qui curvo corpore vel etiam humi sedentes Lithanthracis stratum quattuor tantum vel quinque pedes altum tenebrosa tenuium candelarum lumine prosequebantur magnos eius cubos secantes, qui eodem quo descenderam calatho impositi axi in peritrochio equorum viribus agitato sursum mittebantur. Interea si perniciosum aërem offendant illosve inflammabiles et suffocantes vapores qui gallice *moufettes* vel *feu brizou* dicuntur, tunc alter puteus pluresve venae meandro communicantes aperiuntur, ut data aëri via vaporum accumulatio praepediatur. Irruentes autem aquae extrahuntur ope anthliarum quas tollunt etiam equi, sed praecipue ferventis aquae vapores summa arte vectibus sublevandis applicat<i>. Nec raro occurrit, ut exhausta quadam vena altius in terram penetrent novamque reperiant, qua effossa quoque, ad tertiam usque non dubitant opus continuare. Nullibi autem ditiores fodinae, maiora opera, praestantiora machinamenta, quam Novi Castelli (Newcastle), ubi Lithanthracis stratum quaquaversum et sub ipsum mare ad illimitatas hucusque distantias excurrit. Ibi totum stratum radiatim extrahitur, relictis hic inde intactis ipsius Lithanthracis massis, quae columnarum vice fungentes superiora strata fulciunt et integras non modo familias ab impendente ruina vindicant, sed pagos hominum cum uxoribus ibi ductis liberis ibidem susceptis continuam in subterraneis vitam agentium; quorum nonnulli solem et sidera caeli non nisi fama cognoscunt, in Orcum ante obitum perverso fato delati.

Illorum hominum laboribus eruitur materies illa gemmis si non pretiosior, saltem utilior, quam per totam Angliam cum canalium summis impensis excavatorum ope, tum maris circumlabentis fluctu deferunt; vix enim ullo alio alimento et focos domesticos et fabrorum officinas sustentant, et si ligna haberent Lithanthracem praeponerent. Silvae igitur caducae viles factae segetibus locum fecere, unde magnam frumenti copiam propriis usibus servandam, vel aliis mercibus commutandam colligunt: superfluos etiam Lithanthraces extraneis deferentes auri et argenti vim domum reportant.

Quibus Lithanthracis commodis pensitatis non miror te, Ornatissime Adolescens, desiderare ut iisdem nostra quoque frueretur patria. Et iamdudum viri spectatissimi, patriae utilitatis curam foventes, cupiere ut intra Reipublicae territorium aliqua utilis illius fossilis fodina posset excavari. Eorumque auspiciis et consiliis facta inquisitio causa fuit cur iam a pluribus annis Lithanthracis caracteres in Dynastia de Dardagny animadverterentur.

Quae cum audiissem, ea indicia oculis ipse deprehendere certum habui; ideoque ab ipso Dynasta humanissimo hospitio exceptus silvarum eius custodem sequor et loca omnia quibus primus ille pretiosa Lithanthracis indicia animadverterat lustramus iterum atque attentis oculis admotoque interdum ligone solum scrutamur.

Et primum videmus aquas omnes ex terris illis exsudantes fulvo colore, guttulisque oleosis monstrare petroleum quod Lithanthracis praecipuum est principium, immo late patentia strata arenariorum lapidum quae Genevensi vocabulo *molasse* appellamus tanta petrolei quantitate imbuta deprehendebamus, ut manu pressa oleum guttatim funderent; et finitimi quidam adfirmabant petroleum aestate sponte ex illis lapidibus ita effluere, ut in aquarum stagnantium superficie facili negotio posset colligi. Tandem ad ea loca pervenimus ubi verus Lithanthrax ad telluris superficiem apparet. Nonnulli scilicet abrupti colles in sua declivitate venas exhibent nigras, horizontales, quae tenues quidem, sed veri et genuini Lithanthracis laminas continent, et ex illis frusta haud contemnendae magnitudinis colligere potuimus. Atque huic probatissimo indicio si addas lapidem arenarium ipsum quo constant omnes illi colles indicium esse Lithanthracis, cum fere in omnibus eius fodinis reperiatur; porro si adiungas quod in vicinis locis multae reperiuntur argillae et quidem argillae purit<at>is mixtae; quorum signorum tanta vis est, ut Anglus fossor, licet ne minimam quidem Lithanthracis micam videret, terram excavare non dubitaret; nullus haereo quin, si puteus ibi foderetur, ditissimae optimi Lithanthracis venae reperirentur quarum contenta via regia iis locis proxima exiguo sumptu ad nos deferrentur.

Quanta autem commoda inde perciperet Civitas, dicant opifices et operum conductores, qui norunt quantae pecuniae summae quotannis in carbonem ab ipsis impendantur, quique ex duplicato eius ab initio saeculi pretio eiusdem ulteriora metuunt incrementa, immo egestatem et defectum iure pertimescunt. Dicant quoque ii omnes qui pauperum angustias noscunt quantum frigore saeviente patiantur. Dicant oeconomi quanto pretio veneant omnia quae igne parantur, calx, gypsum, vitrum, lateres innumeraque alia. Quam vili autem pretio venirent, si Lithanthrax ita vulgaris esset ut in quibusdam Angliae provinciis ubi venumdatur pro vigesima parte pretii quo hic lignarium carbonem multo minus efficacem comparamus. Quin immo Anglorum exemplo nova possemus adoriri opificia et Reipublicae calamitatibus imminuta commercia restaurare.

Cum igitur verisimilis existentia Lithanthracis locorum possessores ad eius extractionem sui et publici commodi consideratione invitet, cur non statim operi manum admovent?

Vestrum expectant patrocinium, Proceres amplissimi, sine quo tale opus adgredi nequaquam possibile est. Intermixtae enim iis in silvis, ubi Lithanthrax, possessiones litibus innumeris dum fodinae excavarentur et sub terram perducerentur ansam praeberent, earumque tractationem non modo difficilem sed periculosam susceptoribus efficerent, immo prorsus impedirent nisi edicto futuris iurgiis occurreretur.

Quis autem dubitat, quin Vos, Proceres amplissimi, qui communibus Reipublicae commodis augendis continuam indefessamque navatis operam, qui granaria publica maximis impensis extruitis, qui pauperum egestatibus levandis indesinenter intenti estis, qui numquam non desideratis ut vestris auspiciis floreant commercia et opificia, quique etiam ut praesenti lignarii carbonis defectui succurratis Lithanthraces in opificum usus ex Helvetia accersitis, quis dubitabit quin tali incepto tot bona, si prospere successerit Reipublicae promittenti faveatis et aliquam inveniatis viam, qua istius operis susceptores, iustam securitatem adepti ad illud animose citoque adgrediendum incitentur?

Sed hoc tantae spei inceptum iam undique lacessitum audio obiectionibus, quae etiam apud superiora Consilia urgebuntur, ne res ad prosperum exitum perducatur. Alii scilicet odorem, alii insalubritatem vaporis ex accenso Lithanthrace adlegabunt. Huiusce regionis Lithanthraces pessimae qualitatis esse alii crepabunt, Lausannenses intolerabilis foetoris in exemplum proferentes. At reponam, Lausannenses fossores superiora extraxisse Lithanthracis strata, quae reici debebant, ut in omnibus Angliae et Flandriae fodinis reiciuntur; quod si fecissent et altius in terram penetravissent, melioris notae Lithanthracem certo certius invenissent; neque ad id tentandum imparati erant, sed exortis litibus et pecuniae defectu rem intactam reliquerunt. Quod salubritatem spectat satis erit ut opinor, si praeconceptis vulgi opinionibus Clarissimi Hoffmanni auctoritatem opposuero; ille scilicet post institutam Lithanthracis analysim, eo fine ut de eius salubritate pronuntiaret, his verbis loquitur. "Cernimus igitur manifesto tantum abesse, ut haec principia ullo modo sucis nostris vitalibus infesta sint, ut potius nimias humiditates exsiccando sanguinem et corpus a corruptela et putredine possint defendere. Virtus quippe balsamica, teste Galeno, propria est omni bitumini. Insuper bituminosa omnia accensa aëris vitia emendare et humiditates nimias dissipare ab omnibus ferme medicis creditum hactenus est. In ipsa peste, morbisque contagiosis, ad depurandum aërem, pice, sulphure, asphalto Veteres usi fuerunt." Et paulo infra asserit, Hallam Urbem patriam suam multis endemicis, phtysi, aliisque morbis laborantem ab iis fumo Lithanthracis purgatam fuisse; ostenditque morbos Londini grassantes, quos nonnulli tam gratuito Lithanthraci tribuunt, humili urbis illius situi, iuxta flumen quod bis de die aestu recedente foetidum lutum aëri expositum relinquit, eiusque incolarum numero, alimentis, moribus esse tribuendos.

Hoc igitur metu liberi, Genevensis Lithanthracis extractionem aequis oculis aspiciatis Ornatissimi Auditores! Quin etiam inceptum patriae tantopere fructuosum tueamini et promoveatis! Ipse contentus discedam, si haec oratiuncula carpendae utilitatis nuntium vobis attulerit, et usum eius quantumcumque maturaverit. DIXI.

TRANSLATION INTO ENGLISH OF *ORATIO DE LITHANTRACE*

A Question

Most mountain regions have an abundance of wood, and our country lies in the midst of mountains. I have often been surprised therefore at our housewives' complaints about the expensiveness of wood. At first I was inclined to believe that these complaints sprang from a certain peevishness or over-anxiety about the family budget. But then I was told by the most skilled economists that the price of wood really does go up by leaps and bounds every year, and that there is actually some fear that bad management, responsible for example for the cutting down and uprooting of forests in Savoie before maturity, might in fact drive up the price of a supply necessary for domestic and industrial needs to an intolerable level[1]. I then realised that my criticisms of our housewives had been misplaced, and that they had simply been wanting by timely complaints to encourage their husbands to find remedies. In this regard I often heard also about the prosperity of those areas which have plenty of lithantrax or coal, although from that type of bitumen not only could nourishment be given to our hearths but also fires to our workshops at a tiny cost. This aroused both my curiosity and a desire to secure a new advantage. From that time, I have been extremely eager to know the identity of that fossil coal [*carbo fossilis*], its origin, and in what way such huge masses of it have been able to pile up in the bowels of the earth. I am vexed that such an advantage has been denied to our country, and want to know if there is not some hope of finding veins of lithantrax in the vicinity of our city, and of thus alleviating the shortage of wood which is more to be feared with every day that passes.

Most excellent professor, I know that you have recently spent time in England, with its plentiful supplies of coal[2]. I think that your interest in nature has led you not to neglect a matter worthy of curiosity and attention. At this solemn meeting of this Academy I do not hesitate therefore to put to you my questions, which are of importance for every citizen of Geneva.

Oration

The questions you raise, most honored youth, affect both natural history and economics, and therefore certainly deserve the consideration of this most distinguished assembly. I wish that I were the person to give them a worthy discussion and analysis. But in a few words, as best I can, I will set out the fruits of my own reading, observation and reflection.

Lithantrax or fossil coal (derived from the Greek λίθος, stone, and, ἄνθραξ, coal) is a fossil body from the class of bitumens, black and viscous. Among combustible fuels it preserves heat with great tenacity and duration. There are several types, depending on hardness and purity. It is found at various depths in the earth. In some places, the seams of coal come up to the very surface of the ground. Elsewhere, they sink to two hundred and more yards. Many seams run from east to west, dipping towards the south. They often traverse a great tract of the earth, at first sinking and plunging to greater depths, until at a certain distance and certain depth they become horizontal. In those places, which are called *plateurs* by the French miners, they are very rich and supply the best type of coal. But afterwards they eventually rise again and make for the surface[3].

By what processes was this bitumen formed in the bowels of the earth, and by what cause was it so arranged?

Most modern scholars trace its origin to vegetation, and argue that huge expanses of forest were buried during the great changes endured by the earth, and that because of their long stay beneath the earth they were broken down into a carbon compound[4]. Nor indeed are they bereft of arguments lending a very great appearance of truth to this opinion. For often above strata of lithantrax and in their vicinity are found very obvious traces of plants, exactly the sort of plants particularly growing in forests. Moreover, the texture of lithantrax rivals that of wood at times, to such a degree that some fossil coals are with difficulty at first sight distinguished from charcoals. Again, true and undoubted pieces of wood, and even whole trees, have been found, which seemed entirely changed into lithantrax. Buried pieces of wood have been observed, whose topmost surface had retained the true nature and appearance of wood, while the lower showed as it were broken down wood, and the lowest of all true lithantrax.

These arguments seemed to me most reliable and indeed irrefutable–until I visited coal mines, and by on site inspection I found them at first doubtful, and then unreliable and easily vulnerable to objections.

Why was this? At first I discovered that lithantrax is extremely often found without any traces of plants, and that on the other side traces of plants are found without lithantrax. Then when I examined the texture of fossil coal, I saw that laminae could be observed in them which mimicked the fibers and layers of wood[5]. This can be seen in roofing slate, *l'ardoise*, gypsum, and countless fossils [rocks] which by no means derive their origin from wood. Moreover, that very regular and uniform arrangement in beds precisely overlaying one another and consisting entirely of solid coal does not recall fallen forests undermined and buried, and trees piled up at random. It denotes the traces of nature's slow, lengthy, uniform and ordered action. Granted that at times woods may be found turned into true lithantrax. But do not let that convince you, most honored youth, that it proves all lithantraces spring from wood. The porous and yielding texture of wood could easily be filled with fossil oils and thus acquire the appearance of lithantrax. In a similar way every day we see the same wood turned into marble and even into agate, which is harder than marble, and into a metallic form. Yet no one thinks that marble, agate, metals derive their origin from changed wood.

The natural arrangement of the seams in which lithantraces are found agrees no better with this hypothesis[6]. The seams descend at times in an almost vertical direction into the earth, and thus sink to huge or at least unknown depths, although their extent and thickness are by no means related to such a depth. Often a vein, although very extensive horizontally, is so thin as to form not much more than a mere line. Beneath that thin line are set varied strata of stones, sandstones, and clays, and other seams extend parallel to each other which at times penetrate the hardest rocks. My question is, by what method all these phenomena, which happened not once or twice by chance, but which may be seen in all lithantrax mines, may be reconciled with buried expanses of forests. The actual chemical analysis of lithantrax, if undertaken precisely, completely contradicts its vegetal origin[7]. From lithantrax, as from amber, and all other oily fossils is extracted a peculiar type of acidic, dry salt, which has never been extracted from any vegetal material at all. The ashes from the combustion of lithantrax are quite unlike vegetal ashes.

Regarding that system then as quite overthrown, I pass to something more plausible.

Wallerius, whose opinion in such arguments is of the greatest weight, said that fossil coal was nothing but mud or marl, saturated with phlogiston or inflammable matter. I gladly embrace this opinion[8], except that it is not mud or marl, but rather clay that I think should be recognized as the basis of lithantrax. I hasten to lay the foundations for this opinion.

The way in which lithantrax is arranged in laminae and layers is very similar to the way in which clay itself is organized in its own beds. Fossil coal, just like dried clay, is divided into little sheets parallel to themselves. It is also always found in the vicinity of clay, so that this kind of earth and the stones related to it supply an excellent clue to prospectors. The actual layer of stones directly overlying coal is usually always a type of roofing slate, or *ardoise*, and every expert on fossils [rocks] knows that roofing slate derives its origin from clay. Moreover very often in the neighborhood of lithantrax mines clays are found, which, because they are incompletely saturated with the oily principle, also show incomplete coal and thus the secret of the whole process stands revealed. Meanwhile, the ashes of lithantrax, which we said are so unlike vegetal ashes, completely prove its clayey origin. When they are subject to precise analysis they scarcely offer anything except genuine clay. Many observations also show that lithantrax or at least its original material was laid down along with the remaining strata of the earth during the general changes occurring on the globe. Lithantraces are often found among the strata filled with marine remains, and the constant direction of the seams from east to west, just like the direction of the mountains on our continent, clearly shows that the original material was formed by the same universal cause which built mountains[9], and to that extent must be related to marine deposits rather than to vegetation. The rest of the features having to do with the shape, the site, the thickness of the seams, so contrary to the earlier hypothesis, are in such clear agreement with ours, that it would be quite superfluous to linger over them.

By what process is fossil oil combined with clay, so as to lead to lithantrax ? Neither the warm springs found in so many places nor volcanoes nor earthquakes allow us to doubt the existence of continuous sources of heat in the deep bowels of the earth. Some attribute the source of this heat to a central fire, others to fermentation. During several centuries the theory of a central fire has been in turn accepted and rejected, and lately in the most recent papers of the Paris Academy has been defended by M. de Mairan with new and attractive arguments, which are not however proof against every objection[10]. For long, industrious mine workers, closer to the center of the earth, have seen hot and indeed fiery vapors continuously emerging from the depths of the mines, and have never doubted the existence of a central fire. But if, dismissing these theories, you were to grant, most honorable youth, something about which there is no dispute, that subterranean sources of fire are found in very many places, you will easily grasp that thin and oily vapors seep from nooks and crannies in the bowels of the earth, and cling to those bodies which can hold them, especially to clays, which from their faculty of cleansing are known to absorb fat. Nor will you fail to understand why a great quantity of lithantrax of the very best type is found at the deeper levels, for it is to here that the vapors first come from the inner recesses of the earth, and they only reach the higher levels when those beneath are already saturated[11]. I would gladly follow up with you the corollaries of this hypothesis, did not time summon me to other topics demanding attention. I will add a single observation, lending remarkable support to our hypothesis. There are found in Italy mountains pouring out bitumens of unequal thickness and density, in such a way that the actual roots of the mountain discharge with difficulty the thickest, the more liquid flows from the middle slopes, and the finest, celebrated by the ancients under the name of naphta, oozes from the mountain peak[12]. All this so closely imitates artificial distillation that the caves of the mountain may be called retorts, and the subterranean fires substitutes for a burning furnace.

When these liquid bitumens reach the surface of the earth, they dye the waters flowing from the hills with a rust color, and supply prospectors with an excellent clue to the presence of lithantrax. They drill into the earth, and if they find other promising signs, they immediately hollow out a vertical shaft. It is protected by beams and wooden props against cave-in. Then continuous digging goes on, until a good and rich seam of lithantrax is reached. They use vertical shafts to go down, and to extract coal. I have often been down such shafts in Yorkshire, standing in a basket while fastened to the cable lowering the basket. This method of descent has the drawback that, since the basket swings freely in the shaft, it bangs by turns into the opposite walls; at one moment it grazes one wall, and if it is caught there because of some irregularities, it then in its subsequent headlong descent shakes the terrified passenger to the very marrow. However in this way without harm I reached the seam that was a hundred and more yards deep. After a quite uncomfortable and lengthy crawl along the seam already mined I reached the workers. Stooping or even seated, they were following the seam of lithantrax only four or five feet high in the flickering light of slender candles, cutting great slabs from it. These were loaded onto the same basket in which I came down and sent up by a screw rotated by horse power[13]. Meanwhile, if they encounter deadly air, or the flammable and choking vapors which are called in French *moufettes* or *feu brizou* [14], [*grisou*] then another shaft or several intercommunicating passages are opened in the labyrinth, so that a channel is left for air, and the buildup of vapors prevented. Flooding waters are extracted by the use of buckets also raised by horses, but especially by clever steam engines. Quite often, when a particular seam is exhausted, they go deeper into the earth and find a new one, and when this has been dug out they push on into a third. Nowhere are there richer mines, greater works and more wonderful machines that at Newcastle, where a seam of lithantrax in every direction runs out even under the very sea to distances so far unlimited. Here the whole seam is mined from a central point, while masses of the actual lithantrax are left untouched here and there to act as pillars supporting the seams above. They protect not only whole families from threat of cave-in, but villages of men, with the wives they have taken there and the children they have raised. They spend their whole lives underground. Some of them know of the sun and the stars only by hearsay, and they have been carried down to the lower world by an irony of fate even before they die[15].

By these men's labors is extracted that material which, if not more valuable than precious stones, at least is more useful, which is transported over the whole of England partly by the canals dug with great expense, and partly by sea [so-called sea coal at the time]. They scarcely use any other fuel for domestic and industrial purposes. If they had wood, they would prefer lithantrax. The deciduous forests therefore, losing value, have given way to fields of grain, supplying a crop of great abundance either for their own use or for commerce. Moreover, by exporting lithantrax not needed to foreign markets, they bring back home gold and silver.

I am not surprised, most honorable youth, that in reflecting on such advantages of lithantrax, you long for our own country to enjoy the same. For some time, men of the highest repute, dedicated to their country's advantage, have wanted some mine of that useful fossil [rock] to be dug within the Republic's territory. An exploration made under their patronage and by their advice explains why for several years the characteristics of lithantrax were observed in the estate of the squire of Dardagny[16].

After hearing this, I made up my mind to view those traces with my own eyes. I was most graciously welcomed by the squire himself, and under the guidance of his forest warden I traversed again all the places in which he had first noticed those precious traces of lithantrax; and, with close scrutiny and occasional use of the hoe, I examined the ground.

And in the first place we saw all the waters oozing from those grounds showing by their yellow color and oily drops [the presence of] petroleum, which is the special principle of lithantrax, and we discovered widely spread strata of sandstones, which we Genevese call *molasse*, filled with such a quantity of petroleum that under manual pressure they exuded drops of oil. Some of the local inhabitants declared that in summer petroleum spontaneously flowed from those rocks and could be gathered with little trouble from the surface of pools. At length we came to the place where true lithantrax is visible on the surface. Some steep hills in fact on their slope show black seams, horizontal, containing thin plates but plates of true and genuine lithantrax. We were able to gather pieces from them of considerable size. Add to this most reliable proof that the actual sandstone of which all those hills are made is an indication of lithantrax, since it is found practically in all coal mines. Further, it may be added that in the neighboring places many clays are found, clays of mixed purity; of which clues there is such a great abundance that an English miner, even though he could not see the smallest grain of lithantrax, would not hesitate to excavate the earth. I have no doubt therefore that, if a shaft were sunk there, very rich mines of the best lithantrax would be discovered, whose contents could be brought to us by the royal route nearby at trifling cost.

The advantages accruing from this to our city may be told by our workmen and contractors, who know what great sums are annually spent by themselves on charcoal, and who from the doubling of its price since the turn of the century rightly fear further increases, indeed bankruptcy and failure. They too may tell, who know what hardships the poor endure in the depths of winter, and the economists, who know the great price of everything in whose manufacture fire plays a part: lime, gypsum, glass, bricks and countless other goods. But how cheap could be their cost, if lithantrax were so common as it is in certain English counties, where it is sold for a twentieth part of the cost here of the much less efficient charcoal. Indeed, following English example, we could attempt new industries, and restore the commerce which has been damaged by the misfortunes of our Republic.[17]

Since therefore the probable existence of lithantrax invites the owners of these places to its extraction for reasons both of their own and the national advantage, why do they not immediately apply their hand to the task?

They are waiting for your patronage, most noble dignitaries, without which it is by no means possible to tackle such a work. The multiple ownership of those woods where the lithantrax is located would give scope for countless lawsuits while the shafts were being dug and extended beneath the earth, and mean that their handling would not only be difficult but also dangerous for operators: in fact it would be a complete obstacle, unless a decree were passed to prevent future litigation. Who however doubts that you, most noble dignitaries, in your prolonged and incessant care for the advance of the public advantage—building public granaries at great expense, continually preoccupied with relieving the needs of the poor, always eager that under your protection commerce and industry should flourish, and who, desirous of remedying the current shortage of charcoal, actually import lithantrax from Switzerland[18] for industrial use—who will doubt your support for a plan that, if it goes well, promises so many advantages to our Republic? And that you will find some way so that the undertakers of this work[19], assured of the proper indemnity, may be encouraged to go ahead with energy and speed?

But I am told that this promising plan has been assailed on all sides by objections, to be presented also to Higher Councils, to prevent the scheme from proceeding successfully. Some will allege the stench, others the unhealthiness of the smoke from burning lithantrax. Others will harp that the lithantraces of this region are of very bad quality, adducing as an example those of Lausanne with their intolerable smell. My answer is that the miners of Lausanne have mined the upper layers of coal, which should have been rejected, as they are in all the mines of England and Flanders. Had they done this, and gone deeper into the ground, they would most certainly have found coal of better quality[20]. They were in fact quite ready to do this, but because of lawsuits and lack of money they had to desist. As for considerations of health, it will be enough in my view to oppose to the prejudices of the crowd the opinion of the excellent Hoffmann[21]. After an analysis of coal, intended to deliver a verdict on its healthiness, he reports in these terms: "We see clearly, then, that far from these principles being in any way dangerous to our vital humors, rather, by drying up excess moistures, they can protect the blood and the body from corruption and decay. A quality resembling that of balsam, on the evidence of Galen, is peculiar to every bitumen. Moreover, all bituminous products when burned have traditionally been believed by more or less all doctors up to now to improve the defects of the air and to dispel excessive moistures. Even during a plague or contagious diseases, for the purpose of purifying the air, the ancients used pitch, sulfur, and asphalt." And a little below he declares that his native city of Halle, previously suffering from many endemic diseases, phthisis, and other ailments, has been cleansed from them by the smoke of coal. He shows that the diseases lurking in London, attributed so freely by some to coal, must be attributed instead to the low-lying site of that city, on a river which, as the tide goes out twice a day, leaves stinking mud exposed to the air. He also attributes them to the number of the inhabitants, their diet and their way of life.

Free therefore from this fear, may you look favorably on the mining of Genevan lithantrax, most noble listeners! Protect and advance an enterprise so fruitful to our country! I myself will go away satisfied, if this short lecture has brought to you news of an advantage to be reaped, and has promoted even in a modest way its enjoyment.

The End

ENDNOTES FOR ENGLISH TRANSLATION

1. Deforestation for firewood and for manufacturing charcoal for industrial use was rampant at the time and seriously threatened the environment. The ravages of deforestation continued well into the beginning of the 19th century, particularly in France, although the use of cheaper coal instead of wood was advocated by many authors. See Lefebvre (1802).

2. Reference to Saussure's grand tour of England (February to September 1768) during which he visited coal mines in Yorkshire. See note 12 for more details.

3. The term "*plateur*" is exclusively used for coal-bearing beds of the deeply-buried Carboniferous basin of France and Belgium. They may seem, at first glance, to form an isoclinal sequence trending east-west and dipping toward the south. However, Saussure described them as steeply-dipping southward to great depths, becoming flat (*plateurs*), and then rising again to the surface, displaying so to speak a gigantic inclined U-shaped structure. Such an interpretation was accepted until the 20th century when, after intense mining operations, it was realized that the structure of the basin was extremely complex, consisting of a series of highly-deformed E-W trending recumbent folds and thrusts directed toward the

north. The understanding of this buried complex tectonics became the key for unravelling the structures of the Alps.

In the Carboniferous basin of France and Belgium, when a recumbent fold displays an asymmetrical hinge, the highly inclined overturned stretched limb is called *dressant* and the relatively flat normal and thickened limb *plateur*. The latter eventually thins toward the back of the recumbent fold and is called *queue*. It is true that coal is thicker in the *plateur* than in the *dressant* and can also be of better quality because elsewhere in the recumbent fold, tectonic stretching may lead to changes of bituminous coal to anthracite of lesser quality.

4. This statement about "most modern scholars" interpreting coal as forests buried during past revolutions of the earth refers clearly to the ideas of d'Holbach in the *Encyclopédie* (1753) and in his translation of Lehmann's work (1759).

5. The laminated or banded texture of coal is stressed here in a very clear way and compared with that of shale or slate. In fact this banding results from the alternation of the four major constituents of coal: vitrain, clarain, durain, and fusain which, although corresponding to various types of coalified vegetal materials, do not even represent the fibers and layers of wood. In this section, Saussure started to accept an attitude, today called a sedimentological approach (further developed in the section below), in which he stressed that beds of solid coal are arranged in a uniform and regular way indicating a slow, extended, uniform, and ordered natural process incompatible with the products of destroyed and buried forests.

6. This section contains the following additional sedimentological features that Saussure recognized in coal beds: folding is similar to that of other sedimentary rocks but its geometry is unrelated to the extent or thickness of the beds; individual beds can be both extremely thin and very widespread; association with varied types of rocks such as sandstones (usually underlying coal) and shales or clays (usually overlying coal, see note 8). The stratigraphic succession sandstone-coal-shale and its repetition, which is also mentioned below for the molassic deposits (see note 16), was vaguely reported by some previous authors but not stressed to this extent. It anticipates the modern concept of coal-bearing sedimentary cycles (Bersier, 1945, 1953) which reached their peak development in the Pennsylvanian cyclothems.

7. As seen in the review of previous authors on the origin of coal, chemical analyses at the time were unreliable and certainly not a valid criterion to distinguish bituminous materials from vegetal matters.

8. This statement indicates Saussure's acceptance of the opinion of Wallerius (1750, 1759) that lithantrax consists of shale saturated by bituminous fluids and subsequently indurated. It is followed by comparing coal banding with shale structure and by stating that coal is generally overlaid by shales or roofing slates. Furthermore, if coal occurred among beds containing marine fossils, its original material was related to a marine sediment, that is a shale, rather than a vegetal deposit.

9. The statement concerns coal seams which occurred among marine fossiliferous beds, showing a constant east-west trend like the direction of the mountains in Europe, whose original material was formed by the same universal cause which built mountains. It derived from Saussure's belief that coal was originally a shale subsequently impregnated by bitumen and hence was comparable to any other sedimentary rock involved in mountain building. The idea of an east-west trend may have appeared justified in the Carboniferous coal basin of France and Belgium as discussed above (see note 3).

10. Heat generation at shallow depth inside the crust was generally accepted at the time to explain hot springs, the rising of bituminous materials to the surface, volcanoes, and even earthquakes. Such subterranean processes were assumed to be spontaneous combustion of coal, oxidation of pyrite, or fermentation of buried organic matters. Others considered the effects of a central fire. For instance, the French physicist Jean-Jacques d'Ortous de Mairan (1678-1771) searched for proofs of an internal and permanent source of heat for the earth as the cause of volcanoes (1719, 1765).

11. The idea that the quality of coal increases with depth was recurrent and interpreted in various ways. It is not clear whether it implied that lignite would be underlaid by coal, or whether the quality of a given type of coal would increase with depth.

For Saussure and Wallerius who believed that coal was shale impregnated by rising bitumen, it was obvious that the deeper the coal the better the impregnation. In his review of current ideas, d'Holbach stated that the deeply buried *charbon de pierre* had kept all its bitumen whereas the shallower *charbon de terre*, because of its location and mixture with extraneous materials, had lost most of the lighter fraction of the original bitumen it contained. However, d'Holbach (1753), who derived the bituminous material from the decomposition in place of the resins of the accumulated trees, felt also that more advanced decomposition with depth increased the quality of coal.

These early ideas touch upon the complex biochemical and geochemical evolution today called coalification, which is a diagenetic process causing the various vegetal constituents of original peat to change into lignite and other types of coal as a consequence of compaction, and the geothermal gradient of heat upon burial in a given basin during a given geological cycle and related orogenic events. Whenever a certain grade of coal was formed, it remained unchanged--like any other sedimentary rock which underwent complete diagenesis--unless affected by heat-generating igneous or volcanic intrusions or involved in another subsequent orogenic event. Coalification processes are so complex that it is not possible to demonstrate fully in a given basin (unaffected by any major tectonic deformation) that the quality of coal increases with depth. In fact, the original composition of the vegetal materials appears as a predominant factor, rather than the relative amount of burial. Furthermore, in the 18th century, the structural geology of the various coal basins described in Europe was not yet understood, and the authors did not therefore realize that, at depth, they were looking at Carboniferous coal beds belonging to basins folded at the end of the Paleozoic by the Hercynian orogeny, whereas nearer to the surface they were observing much younger, weakly-folded, or flat Cenozoic lignites belonging to completely different basins. A real geometric superposition of lignites over coals separated by a variable thickness of other deposits existed indeed but it was fortuitous and had no genetic significance.

12. This statement about mountains in Italy spewing naphta of decreasing density with increasing elevation is highly exaggerated and pertains to volcanoes such as Vesuvius and Etna, because at the time bitumens and sulfur were assumed to be their main fuels. It is true that a great variety of gases are released during certain types of volcanic eruptions. A minor amount of them burn with blueish and yellowish flames indicating methane and other hydrocarbons, which probably originate from the natural distillation of bituminous rocks of the regional substratum through which the magma ascended. Whether these parasitic effects reached the stage of petroleum seeps remains to be demonstrated. A vast literature exists on the past eruptions of Vesuvius and Etna as mentioned by Bertrand (1763, pp.93-94), see also Winchilsea (1669) for Etna, and Sorrentino (1734) and della Torre (1755) for Vesuvius.

13. This refers to Saussure's visit to Yorkshire during his trip of 1768 and his descent into a coal mine belonging to Mr. Wedderburns, three miles from Leeds. Details about this descent are described in his unpublished diary (Saussure, 1768). The notes in this diary stopped at Manchester, on September 15, 1768, and the remaining pages of the booklet are blank. The continuation was never found and was perhaps mailed as letters lost by shipwreck in the Channel (Freshfield, 1920, pp.115, 118).

The original text describing the descent of Saussure in the coal mine of Mr. Wedderburns is dated September 3, 1768. It is closer to the truth and describes the behavior of the author in a less romantic and heroic fashion than in the address of 1770. It can be translated as follows: "I went down in this mine, which is 50 yards deep [not 150 yards], by means of a kind of wooden basket suspended at the end of a cable which kept twisting upon itself after being released through a pulley from a wheel operated by one man. In this manner coal was raised to the surface and miners were lowered down. I was standing upright in the basket, fastened by a rope at mid-body to the cable, and thus slowly lowered downwards. Although the descent did not take a long time, I must admit that it was not a boring experience. Indeed, the basket kept hitting either one side or the other of the shaft, and not trusting the rope which kept me attached to the cable, I became tired of holding on to it with my hand. At times, the basket scraping against the walls of the shaft became stuck to some salient and while still being further lowered, it disentangled itself abruptly with very unpleasant jolts. During the descent I managed somehow to observe as much as I could of the irregular succession of strata forming the walls of the shaft.

Upon reaching the bottom, I was given a small candle and strongly bent I walked toward the end of the mine; here and there the tunnel branched off to the right and left. At the working front I met the miners, crouching, pickax in hand, loosening blocks of coal first from underneath, then from the sides, then from above, until falling in mass, they broke a little during their fall. The coal seam was only 3 to 4 feet thick and about as wide [obviously a channel fill]. It was overlain rather abruptly by a black shiny shale, showing little grains on its fracture surface. The shale was rather hard and still somewhat combustible. The coal seam was underlain by a kind of lime rock in which the black color penetrated 2 to 3 lines deep, but it became whitish deeper [probably an underclay].

I collected samples of all these rocks and exited the mine in the same manner as I had entered it but more courageously and with less trouble. At the surface I leisurely examined large blocks of coal extracted from the mine. They clearly showed what I had previously seen at depth, namely that coal occurred in horizontal or weakly inclined beds. The coal was also divided into individual sheets of variable thickness separated by whitish, sometimes ochreous sheets of pyrite. The regularity of these coal seams and their enormous amount make it difficult to understand how they were formed [this was the first time that Saussure, 28 years old, had observed coal measures. He was apparently entirely unaware of the origin of these rocks and of the abundant related scientific literature. The text of his address of 1770 shows that he surveyed the question rather effectively less than two years later].

My wife and Mr. Wedderburns who had reached by carriage the edge of the shaft were impatiently waiting for me. My wife laughed at my tattered coal heaver outfit particularly because I was also wearing a miner's helmet. Then we went to see a steam engine which pumped out the water from the mine I had just visited... [a long technical description of the engine and its operation is omitted here]. All the surrounding countryside is full of coal. The soil is black, flaky and lacking vegetation in many places. This situation encourages exploration by augering followed by digging when traces of coal are observed in the cores."

14. Fire-damp, a combustible gas consisting mostly of methane occurring in coal mines, is dangerously explosive when mixed with certain proportions of air. For naturalists who believed that coal was shale impregnated by rising bitumens caused by subterranean fires, fire-damp was proof of the existence of their volatile portions mixed with air in mines (see F. Hoffmann, 1695 quoted in E. Bertrand, 1763, p.125; *Encyclopédie*, 1756, Article "Exhalaisons").

15. This statement is not corroborated by contemporary evidence. There were no underground "troglodytic" villages of this kind, although the Children's Employment Commission of 1842 reported that women and children were employed in mines for long hours under dreadful conditions (Bryant, 1953). They lived however on the surface, in poor hovels in a polluted environment. Either Saussure heard about women and children underground, and, since he could not believe that they were working there, concluded that there must be underground communities of villagers; or he wanted to assure the establishment of coal mines on the territory of Geneva under more humane conditions because of his lifetime interest in the improvement of the social status of the working class (Freshfield, 1920, Carozzi, 1976). Therefore, he presented a romantic traveler's tale about English conditions.

16. The following sections deal with coal and petroleum seeps occurring in the Chattian (Oligocene) freshwater variegated sandstones of the molasse in the region of Dardagny, near Geneva. The peculiar nature of coal encountered in the molasse of the Swiss plateau in general, particularly in its Oligocene portion (Dardagny, La Paudèze and Belmont, near Lausanne where it was actively mined from the 16th to the 18th century, to cite only a few locations mentioned for instance by Scheuchzer, 1716-1718, 1746) appeared to confirm the concept accepted by Saussure that coal was a shale impregnated by bitumen. Indeed, as pointed out by many recent authors (see Heim, 1919, Bersier, 1968), the coal of the molasse has all the chemical and calorific properties of lignite or brown coal, but it is not soft and brown, but instead black, friable, and shiny, showing no remains of original vegetal materials and resembling a subbituminous coal. The friability and black color is due to its high content of fine iron sulfide particles. It is understandable therefore that this coal was designated by Saussure as "true and genuine lithantrax."

The interpretation of coal in the molasse at Dardagny, which occurs in seams reaching up to 1 m thickness, was compounded by the fact that the enclosing porous sandstones show not only seeps of relatively dense bitumen but also thin pitch-black layers of jet (ozokerite) along their bedding planes. They represent the end product of polymerization of bitumen and resemble also, at first glance, thin layers of coal. It may well be that when Saussure talked about "thin plates but plates of true and genuine lithantrax" he may have seen first the ozokerite which led him to the seams of coal from which he collected "pieces of considerable size."

This curious association can still be seen today near Dardagny in a little stream appropriately called Nant Punais (stinking stream), a tributary of the Nant Roulavaz, which flows into the Allondon River which in turn flows into the Rhône.

The origin of the bitumen seeps remains controversial. The oil seems to have migrated upwards from deeper marine bituminous shales (Mesozoic or Early Cenozoic in age) into porous molassic sandstones whereas coal is autochthonous and represents an aspect of the freshwater sedimentation of the molasse.

The search of Saussure in 1770 for lithantrax beds in the variegated molasse of the Dardagny area (*Voyages dans les Alpes...*, 1779, vol. I, § 64) led to the first reports on oil seeps in the Nant Punais

(Carozzi,1992). Local farmers had been digging shallow wells in the valley probably since the 17th century, extracting oil floating on the surface of the water for medicinal purposes, or for lubricating cart-wheels and waterproofing boats. Subsequently, three drifts were excavated in the flanks of the Nant Roulavaz from which heavy oil still oozes out today. Nevertheless, all attempts at commercial production failed.

Saussure, after having stressed the association of the coal of Dardagny with sandstones and shales which was comparable to that of other coals, suggested the sinking of shafts at greater depth, following the idea discussed above (note 11) that better and thicker coal seams would be found at greater depth.

In that respect, the archives Saussure (MS 81, No. 10) contain the copy of an apparently unpublished set of notes, ten pages long in English, on the detailed succession of the various types of rocks overlying coal in several major coal basins of Great Britain. These notes were written by Bengt Quist Andersson (? - 1799), director of refined steel industry of Sweden, member of the academy of natural history of Stockholm and author of several papers on geology. Inserted in these notes is a loose sheet written by Saussure entitled "Fossil coal" which can be translated as follows: "Mr. Quist, called Salner of Stockholm, is convinced that coal deposits should occur in our neighborhood. He has always found quarries of molasse (sandstone) and of clay [shale] overlying coal beds. It would be necessary to drill or to dig in these quarries. If one would find sheets of molasse stained by a shiny black color, as I saw near Pregny at the place called La Pierrerière, this would be an excellent clue [of the occurrence of coal at depth]. However, the best clue would be to find clay [shale] mixed with pyrite. On the contrary, the worse situation would be to encounter limestone; in such a case the shaft should be abandoned."

17. This refers to the industrial and commercial inflationary overexpansion in Geneva during the second half of the 18th century, which caused inflation and was followed by stagnation due to increased custom duties and protectionist measures taken by several countries of the Holy German Empire as well as by France. These countries were the major importers of the manufactured products of Geneva, mainly watches and printed cotton fabrics (*indiennes*). This economical crisis, heralding the end of the *ancient régime*, was further exacerbated by constant political troubles between the aristocratic oligarchy and the people.

18. Geneva was an independent republic, not a member of the Swiss Confederation, until 1815.

19. Saussure's plea remained without effect. Indeed in 1771, he promoted a corporation consisting of 25 interested subscribers who gathered 400 *louis d'or* for the exploitation of "tar and coal." The attempt failed because of disagreements with the owners of the land about the potential profits of the venture (see *Voyages dans les Alpes...*, 1779, vol. I, footnote to § 64).

20. This is a repetition of the above-discussed idea of the quality of coal increasing with depth (see notes 11 and 16).

21. In his effort to promote the proposed mining venture, Saussure summarily dismissed here the frightful industrial pollution generated by burning high-sulfur coal during the industrial revolution in Great Britain and Germany solely on the basis of the personal and, then already highly debated, opinion of Friedrich Hoffmann, called the Younger (1660-1742). He was a famous physician and a prolific writer from Halle who had published (1736, also quoted in the *Encyclopédie*, 1753, vol.3, p.194) on the assumed health benefit obtained from breathing the sulfurous fumes of burning coal! He subsequently (1754) toned down his ideas but Saussure was apparently unaware of it.

EVALUATION OF SAUSSURE'S CONTRIBUTION ON THE ORIGIN OF COAL

Saussure accepted Wallerius' and Bertrand's opinion that coal was a shale impregnated by bituminous fluids rising by the effects of subterranean fires. In his review of opinions on the origin of coal up to his time, Saussure presented a structural interpretation of the Carboniferous coal basin of France and Belgium which remained valid until the 20th century when the existence of recumbent folds and overthrusts was recognized, bringing a revolution in structural geology. Only then was it possible to reach an understanding of the structure of the Alps.

Saussure stressed, even more than Bertrand, the typical laminated or banded texture of coal and its major sedimentological and stratigraphic features which indicated to him that coal was originally a marine deposit, a shale, similar to other sedimentary rocks and not a submerged or destroyed forest. He also emphasized that coal belonged to repeated sequences of sandstones and shales or clays, a concept foreshadowing modern ideas on the cyclicity of coal-bearing deposits.

On a local scale, Saussure faced unusual geological circumstances represented by the Chattian freshwater molassic sandstones at Dardagny with intercalated beds of an unusual type of black lignite devoid of visible remains of vegetal materials, and therefore resembling subbituminous coal, in his own words "genuine lithantrax." Furthermore, these sandstones ooze heavy petroleum and contain thin intercalations of pitch-black jet (ozokerite) or polymerized bitumen also resembling coal. The combination of these conditions conspired to make him believe that it represented a perfect demonstration of the idea that coal was a shale or clay impregnated by bituminous fluids rising as a consequence of subterranean fires. In his time, Saussure could not have realized that the association of bitumen with coal was purely fortuitous, namely that the upward migrating petroleum accumulated in the porous molassic sandstones which happened to contain beds of a peculiar black lignite mimicking coal.

Following the idea that the quality of coal was supposed to increase with depth, an idea particularly supported by those in favor of rising bituminous fluids, because they would impregnate more heavily the deepest layers of shale, he strongly promoted to his audience the economic benefits which deeper mining operations of local coal would bring to the ailing industry of Geneva. The only problem he foresaw was litigation with the land owners and he hoped that it would be prevented by legal means. Unfortunately, the "most noble dignitaries" did not act, and the mining venture never materialized.

Saussure was well aware of the threatening effects of widespread deforestation brought about by gathering firewood and manufacturing charcoal for industrial use, and had what would be called today "environmental concerns." Therefore, he was so eager to promote his mining venture and the use of cheaper coal in general, that he recklessly misled his audience into believing that breathing sulfurous fumes from burning high-sulfur coal would be beneficial to their health, relying for that purpose on the quaint opinion of a then well-known German physician.

THE AFTERMATH

The general approach to the interpretation of the origin of coal was somewhat improved by Buffon in the *Époques de la nature* (1778) and later on in the *Histoire naturelle des minéraux* (1783-1786). He felt that a gradual transition existed between lignite and coal, and that all types of coal were marine deposits consisting of an intimate association of vegetal debris and bitumen--which was interpreted as liquid vegetal oil or animal fat-- subsequently indurated by the mixture of acids. Sulfur released upon combustion of coal was assumed to originate from enclosed pyrite.

However, the modern understanding of the origin of coal as the product of the carbonization *in place* of original peat, emerged through the extensive field work of Franz Von Beroldingen (1778, 1792-1794, Erster Versuch) who was indeed the first to state that coal originated from lignite and lignite from peat, thus equating coal beds to the various types of peat swamps buried by subsequent marine or freshwater deposits. He also stressed that the bituminous constituents of coal and peat originated from fermentation of vegetal materials and not from the formerly assumed addition of petroleum to a sediment.

Johann David Schöpf (1787) followed this interpretation by stating that the Carboniferous coals of eastern and western Pennsylvania originated unquestionably from accumulations of peat or peaty soils which underwent fermentation and compression. He quoted the work of Von Beroldingen (first edition of 1778, p.106) as his source.

Jean-André Deluc in 1778 (the same year as Von Beroldingen), after extensive travels, and in the last of his five letters describing the peat deposits of northern Europe, reached a similar conclusion, namely that coal derived from buried and compressed peat submerged under the ocean (p.223-226). However, he stated in a footnote (p.226) that, although he had been anticipated by Von Beroldingen, he had reached the same conclusion independently while studying the immense peat bogs of Bremen. Deluc emphasized that the change of peat to coal was a complex and yet poorly understood process which occurred "in a laboratory he did not know", yet it was the true explanation of the origin of coal.

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