AMI BOUÉ'S (1794–1881) VALUATION OF GEOLOGICAL RESEARCH REGARDING ITS APPLICATION TO HUMAN CIVILISATION

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ABSTRACT

Ami Boué held a holistic view in his approach to geological research. Thus, he emphasised the significance of geosciences for the development of civilisation and in several publications he outlined the connections between geological knowledge and understanding the development of civil infrastructure and agriculture. In the present paper, special consideration is given to Boué's approach to mineralogy and mining, both closely linked to geological knowledge, as well as to his construction of two geological maps of the terrestrial globe—the first of their kind. For these, he used his personal experience, his detailed knowledge of the geological literature, Elie de Beaumont's tectonic ideas, and numerous analogies between different parts of the world. He underscored the significance of mineralogy and mining in the era of industrialisation, but at the same time advised against too rapid an exploitation of mineral resources. By strongly promoting the training of miners in theoretical geological knowledge he tried to prevent worthless mining enterprises.

1. INTRODUCTION

Ami Boué (1794–1881) (see Figure 1) was a geologist who, ideologically, was strongly influenced by the Industrial Revolution. He recognised the call for scientific research, not merely as '*l'art pour l'art*' but as a prerequisite for any development of civilisation, particularly during the period of industrial development in the nineteenth century, be it economically, medically, politically or culturally motivated. It was one of his life principles to propagate this holistic approach among scientists and any other groups that might be involved in the practical applications of scientific discoveries.

Detailed information about Boué's career may be found in his autobiography (Boué 1879). Born in Hamburg on 16 March 1794, Boué was descended from a Huguenot family from Bergerac (Dordogne). His great-grandfather, Jacques Chapeaurouge, moved to Hamburg in 1705 and became a wealthy owner of a shipping company, which offered Boué a comfortable childhood. He received his initial education in Hamburg and Geneva and later, between 1814 and 1817, he studied natural science, along with medicine and botany, in Edinburgh. However, his interests soon inclined towards science rather than medicine, though he continued his medical studies. He received much scientific encouragement from the Edinburgh Professor of Natural History, Robert Jameson (1774–1854), who motivated him to explore as much as possible of Scotland. These excursions led him to publish a geognostic description of the country including a coloured geognostic map (Boué 1820). This publication opened his scientific career.

After leaving Edinburgh, Boué continued his studies in Paris, Berlin and Vienna from 1817 to 1826. Besides his work in these cities, he travelled through the Auvergne, the south of France, Germany, Austrian Hungary, and Italy. These journeys resulted in an essay, published in 1822, comparing the geognosy of Germany with that of Scotland (Boué 1822). The essay was extended to a monograph in 1829, in which Boué described the various formations recognised thus far in Germany, and their distribution (Boué 1829). The work aimed at offering a complete geographical–geological picture of the Earth's past, comprising all that was known up to 1826, discussing crucial new discoveries in the Alps and various Tertiary basins. Important for Boué's further scientific development in Paris were his acquaintances with Pierre-Simon de Laplace (1749–1827), Georges Cuvier (1769–1832), Barthélemy Faujas de Saint Fond (1741–1819), Etienne Geoffroy de Saint Hilaire (1772–1844), René-Just Haüy (1743–1822), and Alexandre Brongniart (1770–1847). A journey to Berlin brought him in contact with the mineralogist Christian Samuel Weiß (1780–1856), from whom he received further information in the fields of crystallography and mineralogy. In Vienna, Boué met Friedrich Mohs (1773–1839), who had already elaborated his famous mineral system. Together with Franz Xaver Maximilian Zippe (1791–1863), mineralogist at the Bohemian National Museum in Prague, Boué undertook excursions to several regions of Bohemia looking for new mineral deposits.

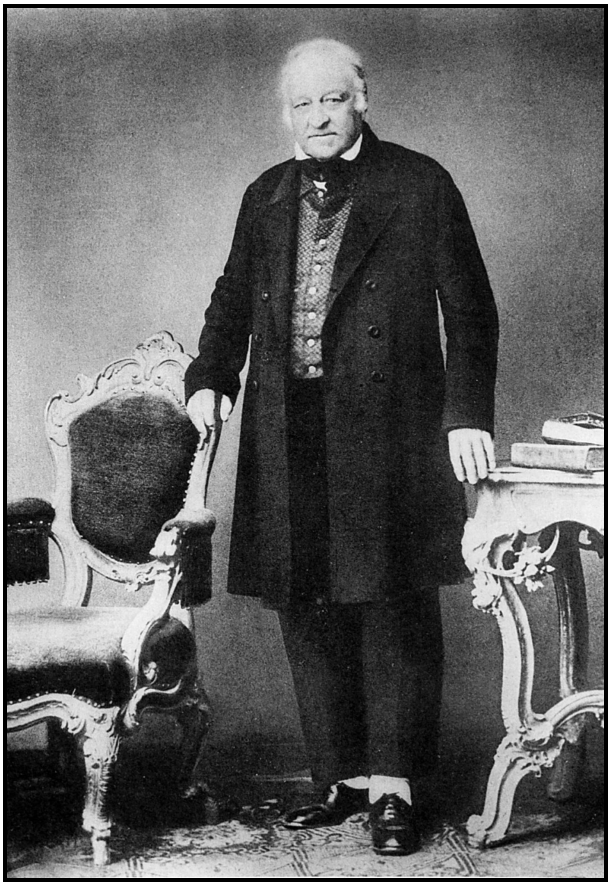

Figure 1.
Ami Boué (1794–1881).
From archives of the Société Géologique de France.

In 1826, Boué married Eleonore Beinstingel in Vienna, with whom he spent a period in Berne, before settling in Vöslau (Lower Austria). One of Boué's accomplishments was the foundation of the *Société Géologique de France* in 1830, in association with Constant Prévost (1787–1856), Gérard Paul Déshayes (1795–1875), and Jules Desnoyers (1800–1887) (Durand-Delga 1997a). On behalf of the Austrian Government he geologically explored European Turkey, Serbia, Croatia and Bosnia in three expeditions during the years 1836 to 1838. These journeys resulted in three pioneering works (Boué 1840a, 1852, 1869a), not only on the geology of European Turkey but also on its archaeology, geography, ethnology and politics. Boué's geological observations assisted the establishment of a rail network in that part of the world (Seidl 2002). The vast range of subjects addressed in his works underscores Boué's holistic and wide-ranging knowledge and understanding of the significance of science in the development of civilisations.

2. BOUÉ'S GEOLOGICAL IDEAS AND GLOBAL GEOLOGICAL MAPS AND THEIR GENERAL IMPLICATIONS

Before discussing Boué's approach to geological research, a more general question should be asked: what, in his view, were the general implications of geological research? To begin with, it should be mentioned that he held a critical view of geologists who treated geology on merely theoretical grounds. And he particularly criticised certain unnamed British professors who related their theories to their religious beliefs:

> While geological science makes genuine advances in British countries, many theologians there continue to confound, in the most ridiculous manner, biblical narratives with geological facts that are as well substantiated physically as any problem in mathematics (Boué 1832, p. lxxv).[1]

It is obvious that this reproach was chiefly addressed to William Buckland (1784–1856). However, Boué does not appear as a categorical opponent of theoretical principles (see also Laurent 1993). On the other hand, consulting his publications, it is immediately striking that he related his geological investigations chiefly to their influence on the economical, cultural, medical, and even historical parameters of a country. In other words, he regarded the Earth sciences not as isolated disciplines, divorced from the economy and humanities. Rather, he attempted to relate geoscientific research to its impact on human culture in its widest sense. This approach was also expressed in the title of a long essay, which systematically and in detail outlined his holistic valuation of geology: *Der ganze Zweck und der hohe Nutzen der Geologie, in allgemeiner und specieller Rücksicht auf die österreichischen Staaten und ihre Völker* (*The Purpose and Elevated Benefit of Geology in General, With Particular Regard to the Austrian Countries and their Peoples*) (Boué 1851a), which will be discussed below. In the introduction to the same essay Boué claimed:

> This science [geology] is related to many others, as it could not exist without a vast multitude of different facts. Its sources comprise not only nearly all branches of physical, chemical and other natural sciences, but also the assistance of geography, ethnography, archaeology, history, statistics, the medical sciences, and even philology are required for its support. Thereby it becomes a kind of tie between these very disparate areas of human inquiry (Boué 1851a, pp. v–vi).[2]

It is interesting to remark that with this approach he represented a view that had been advanced in the previous century by Charles de Secondat, Baron de Montesquieu (1689–1755), though Boué did not explicitly refer to him. Montesquieu's basic historical–philosophical concern was the explanation of a country's political development on the basis of its external and internal factors. As external factors, he considered size, geographical parameters and climate, while internal factors were constituted by a nation's character, religion, and customs. He first outlined this position in his *Considérations sur les causes de la grandeur des Romains et de leur décadence* (*Considerations on the Causes of the Splendour and Decline of the Romans*), first published in The Netherlands in 1734 (Montesquieu, 2nd edn 1748). He further elaborated his ideas in his principal work *De l'ésprit des lois* (*The Spirit of the Laws*) (Montesquieu 1749),

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1 Si la science géologique véritable avance dans les pays anglais, bien des théologiens y continuent de confondre, de la manière la plus grotesque, les récits bibliques avec des faits géologiques prouvés physiquement aussi bien que tout problème de mathématique.

2 Diese Wissenschaft ist mit vielen anderen verbunden, weil sie ohne eine große Mannigfaltigkeit von verschiedenen Thatsachen nicht bestehen kann. Ihre Quellen sind nicht nur fast alle Zweige der physikalischen, chemischen und Naturwissenschaften, sondern Geographie, Ethnographie, Archäologie, Geschichte, Statistik, Medicinalwissenschaft so wie selbst die Philologie müssen ihr Hilfsmittel gewähren. Dadurch wird sie eine Art von Bindemitteln zwischen diesen sehr verschiedenen Forschungen des menschlichen Geistes (Boué 1851, pp. v–vi).

which gave expression to social and political ideas that were at the time somewhat revolutionary and were not well received by the absolutist government of Louis XIV. Boué's approach related to the first part of *De l'ésprit des lois*, which explained the relationships between external natural factors and the ecology, economy, and anthropology of a country (Montesquieu 1749, Vol. 1). And 150 years after Boué, Jared Diamond has published his popular book *Guns, Germs, and Steel: The Fates of Human Societies*, which offers somewhat analogous ideas (Diamond 1997).

Boué adopted a holistic approach to the question that Diamond posed, namely whether "History followed different courses for different peoples because of differences among peoples' environments, not because of biological differences among peoples themselves" (Diamond 1997, p. 25). However, unlike Boué, Diamond does not claim geology as the crucial scientific discipline for answering cultural–anthropological questions of the kind stated above. Rather, he mentions geology as but one among various scientific disciplines "in particular, . . . [the] historical sciences such as evolutionary biology and geology" (Diamond 1997, p. 26). It must be added that Diamond, as compared to Montesquieu, considers different parts of the world and provides a more complex set of explanations than Montesquieu's idea of a cultural north–south gradation. As said, Boué never specifically mentioned Montesquieu, and neither does Diamond. Moreover, Montesquieu's ideas had chiefly been developed by a non-scientist, but they were independently supported by the different perspective of Boué as a geologist.

With 'Montesquieuesque' ideas in mind, then, Boué emphasised the importance of combining scientific theory with its practical application, thus going beyond the bounds of mere intellectual scientific curiosity. His respective publications were characterised by their regard to more general geological considerations as well as their treatment of specifically selected topics. Confining ourselves to his most significant work, we examine first his long essay *Der ganze Zweck und der hohe Nutzen der Geologie* (Boué 1851a). In this work, Boué pointed to the practical applications of geology, particularly in mining but also in its cultural contexts, as for example in the planning of rail routes. As to their importance in mining, he followed in the tradition of the Wernerian school at Freiberg, which according to Archibald Geikie "put mines before mountains" (Geikie 1962, p. 239)—though, needless to say, Boué had fifty years of additional scientific knowledge available, compared with what was known in Werner's (1749–1817) day.

The planning of rail routes formed only one of the items needed to meet the needs of a nation's efficient economic development in the nineteenth century. But it was evident that it could only be achieved successfully on the basis of geological maps. And these greatly interested Boué. After having published his maps of Scotland (1820), Europe (Boué 1827), Austria and South Bavaria (Boué 1830a, pp. 64–67), Moravia and the northwest of Hungary (Boué 1830b, p. 223), Transylvania (Boué 1831, pp. 242–244), as well as Turkey (Boué 1840b), he even had the temerity to produce a geological map of the globe, first as a manuscript map exhibited at a lecture at the Congress of German Scientists and Physicians (*Versammlung deutscher Naturforscher und Ärzte*)[3] in Graz (Austria) in 1843 (Boué 1843; see Figure 2), and subsequently published with some revisions in 1845 (see Durand-Delga 1997a, 1997b) and in 1846 (see Figure 3). In 1845, Boué used a topographical map of the world by Carl Ferdinand Weiland (1782–1847), the leading cartographer of the Geographical Institute in Weimar, using Mercator's Projection (Weimar 1841) (reproduced in part by Durand-Delga, 1997b). Another version was published in English in 1846 by the Scottish cartographer Alexander Keith Johnston (1804–1871) (see Figure 3). All this was pioneering work. (Johnston was mistaken in indicating on his map that the Graz map was from 1844.)

The 1846 version showed in the bottom left an illustration of Léonce Élie de Beaumont's theory of mountains (Élie de Beaumont 1829–1830). As with Boué's approach fifteen years after

[3] The *Versammlung deutscher Naturforscher und Ärzte* was a symposium, founded in 1822 by the medical doctor and scientist Lorenz Oken (1779–1851). It was held every year in different cities of the German-speaking areas of Europe and was divided into scientific and medical sections (Hoppe 2002, pp. 125–274). The meeting in Graz was organized by Archduke Johann of Austria.

this publication, he had sought a general, indeed global, explanation to account for the development of mountains and explained the folding of the Earth's crust as being due to the contraction of the globe as it gradually cooled, comparable to the wrinkles formed by an apple while gradually drying out (cf. Oldroyd 1998, pp. 237–240). The foldings eventually resulted in ruptures and clefts. Comparative studies of the folds in different regions of the world, suggested that they could be divided into different 'systems' and arranged in chronological order according to the degree of folding and the observable unconformities, as shown in the figure accompanying the map. Thus the "Netherlands System" exhibited only slight elevations above sea level while elevation becomes more evident in the "system of the Pyrenees and Appenines", eventually reaching extremes with the "system of the principal chain of the Alps". The map also contained an inset showing numerous supposed parallelisms of mountain ranges, in a manner sanctioned by Élie de Beaumont's theories.

Élie de Beaumont developed his mountain elevation theory to provide an explanation for Cuvier's theory of catastrophes, considering the revolutions of the Earth to have been the consequence of global cooling and episodic contraction. His theory should therefore be judged as 'catastrophist'. Later, however, Élie de Beaumont elaborated his theory in terms of more gradual changes of the Earth's surface (Oldroyd 1998, p. 238). On the other hand, he imagined more order or regularity in the Earth's mountain systems than was actually there: he came to think that the mountain elevation zones were distributed as fifteen half circles around the globe, which crossed each other and thus formed a regular pattern of intersections, which (Élie de Beaumont 1852) he called a *réseau pentagonal* (pentagonal network) (Oldroyd 1998, p. 239). But this idea, though depicted on one of his maps, was never satisfactorily documented by facts. Be this as it may, Boué's map shows his basic acceptance of the importance of Élie de Beaumont's thinking *and* the continuing influence of Werner's ideas in the German-speaking world, as can be seen from the Wernerian terminology surviving in the Boué map.[4] In 1844, Boué published a memoir about his geological ideas and on the development of the global geological map that he had presented 1843 at Graz and revised for its publication in 1844 (Boué 1844).[5] Therein he referred to Élie de Beaumont's mountain theory—though without actually mentioning his name (Boué 1844, pp. 308–309). In particular, he drew two conclusions from this theory: (1) that similarity in the direction of mountain chains allowed—to some extent—conclusions about their geological constitution and that of their neighbouring rocks (Boué 1844, p. 308); and (2) that parallel mountain chains are of the same geological nature if separated by valleys or branches [of the sea], igneous rocks, or by Secondary or Tertiary basins (Boué 1844, p. 309). He added a long list of examples from various parts of the world, considering mountain chains that run in parallel—both from east to west and north to south (Boué 1844, pp. 309–312). Thus, he claimed, broad geological generalisations could be made on the basis of topographic maps.

In the same paper, Boué indicated that he had based his global map on geological and geographical information that he had collected over twenty-eight years (Boué 1844, p. 297). And for fifteen years he had been compiling a *Relevé bibliographique général et méthodique des sciences physiques naturelles, géographiques et géologiques*.[6] At the end of his paper, Boué listed the sources he had used for the information on his map. However, he admitted that the

4 Boué had not, however, always been in accordance with the periods to which Élie de Beaumont assigned his elevation zones (Boué 1831, 338–359). He particularly criticised Élie de Beaumont's denial of the periodic recurrence of elevations with the same orientations and interpreted this attitude as "a ridiculous concession to the dogmatic views of the clergy" (*une concession ridicule aux opinions dogmatiques du clergé*) (Boué 1879, 23), as it supposedly implied Noah's Deluge. In fact, as he stated in his autobiography, he changed his mind on various matters quite often, and his re-evaluation of Élie de Beaumont seems to have been an example of this.

5 The map Boué referred to corresponds with the map published by Durand-Delga (1997b). In his paper, Boué stated that copies of his map could be purchased from M. Andriveau-Goujon in Paris for four francs, but only by Members of the *Versammlung deutscher Naturforscher und Ärzte*.

6 *General and Methodical Bibliographic Summary of Physical, Geographical and Geological Sciences.*

published information had been scattered in all sorts of journals, which he had not always had the opportunity to access (Boué 1844, pp. 367–371).

For New Zealand, for instance, there was no indication as to where Boué obtained his information. He could perhaps have used Ernst Dieffenbach's *Travels in New Zealand* (Dieffenbach 1843; Oldroyd 1999, p. 24).[7] But in fact it appears that, according to Durand-Delga's (1997b) investigations and Boué's statements in his paper, he coloured his map to a considerable degree according to his theoretical expectations (especially relating to the parallelism of mountain chains and the forms of land masses) as much as ascertained geological information. Thus his maps displayed what Boué 'thought would be there', according to analogies with parts of the globe previously described by other geologists. A curious example was provided by his belief that because southern Africa and India have an analogous triangular form there should be an analogue of the Deccan traps in Africa (Boué 1844, pp. 348–349). In the 1843 map the hypothetical African traps were shown as an uncoloured circle with a red boundary. By the time of the Johnston map, however, there was a clearly-delineated and coloured area of basalt in the middle of Africa. It is not clear to us that additional empirical information had become available by 1846 to warrant this firming of opinion.

Be this as it may, and with the map necessarily being speculative for many parts of the world, it was a heroic effort to attempt to produce a global geological map as early as the 1840s. The project illustrates the large canvas on which Boué laid out his ideas and was in a sense in keeping with his general holistic view of the world—but here of course in the sense of grand geological generalization rather than the interdisciplinary valuation of geosciences and views on the interconnectedness of all forms of knowledge.

Returning to practical matters of social importance, Boué thought that economic success depended on the availability of clean water and appropriate soil for agriculture, and appropriate material for building houses, apartments, and industrial and official buildings. A network of roads had to be created over the whole country, and eventually the illumination of populated areas was needed to ensure citizens' mobility after sunset. All these requirements, Boué claimed, could only be founded on one science—geology and geognosy.

The need for a variety of stones for sculpturing connected geosciences to art. Pigments were needed in painting and were provided by nature, as for example cinnabar. Boué's catalogue of the economic, agricultural and artistic factors that were based on the geosciences was long. It comprised—besides the already named examples—the manufacture of pottery, dependent on ample resources of clay. Moreover, archaeology needed to determine the types of sediments in which archaeological relics are embedded. Naturally, agriculture was mentioned, which could only be successful if there were enough underground watercourses available. Navigation could only be undertaken without ships being wrecked if the geological circumstances along coasts, as well as the locations of submarine rocks, were well known.

7 Dieffenbach (1792–1847) was a ship's surgeon and naturalist who visited New Zealand in 1839 and made some geological excursions, mainly in the North Island.

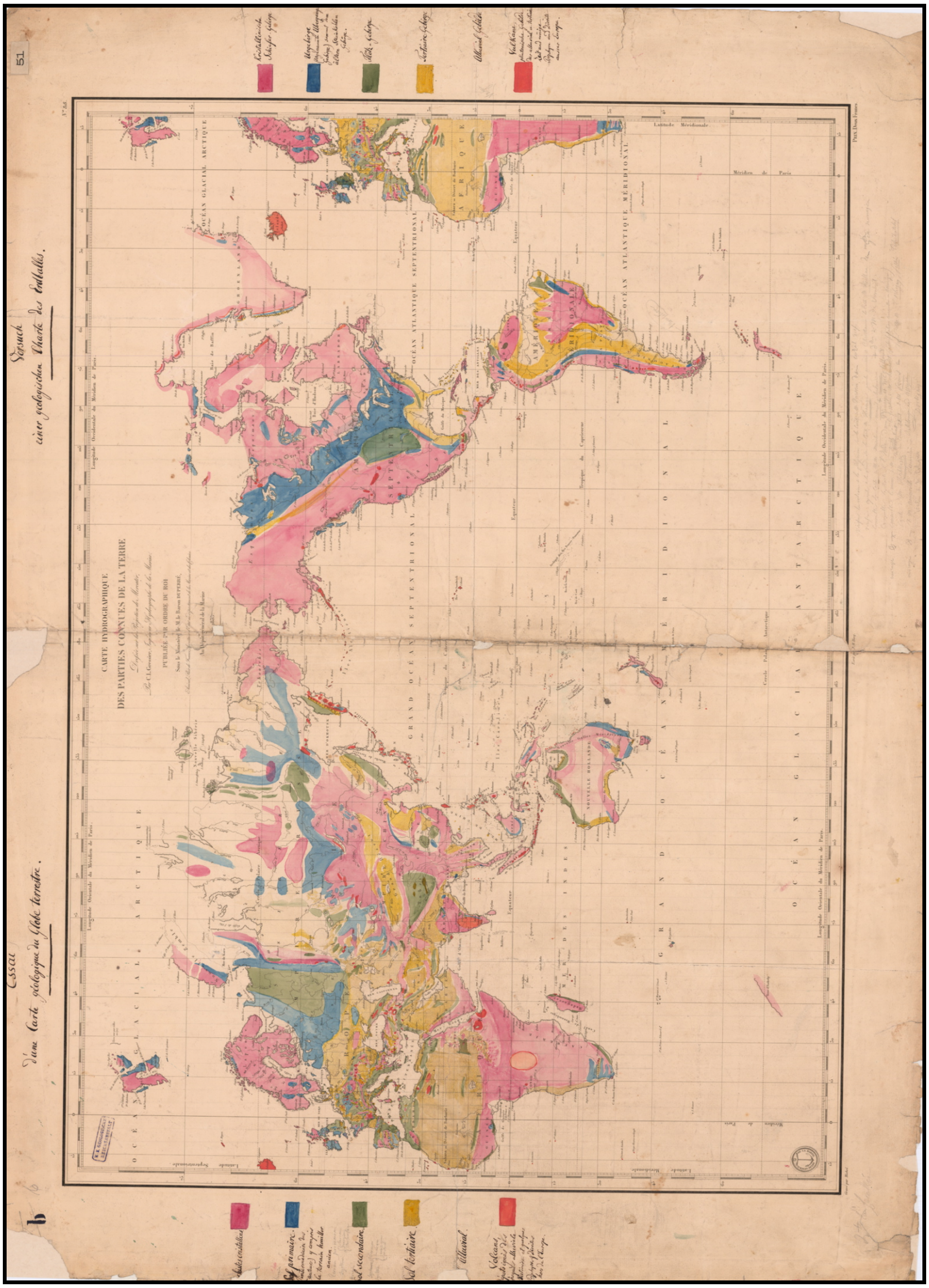

Figure 2. Boué's manuscript geological map of the world, exhibited at Graz in 1843. Base map by C. I. Gressier for the Dépot général de la Marine*, 1833. Key: Red,* Kristallinische Schiefer-Gebirg*; Blue,* Urgebirge *and up to Lower Carboniferous; Green,* Flötz-Gebirge*; Yellow,* Tertiär-Gebirge*; Uncoloured, alluvial deposits; Red, volcanoes, plutonic rocks, and extra-European porphyries and diorites. By courtesy of the Austrian Geological Survey (Sig. KIII 1157). This map usefully shows the different stratigraphic terminologies favoured in Eastern and Western Europe at that period:* Schistes cristallins/Krystallinische Schiefer-Gebirge*;* Sol primaire/Urgebirge*;* Sol secondaire/Flötz-Gebirge*;* Sol tertiaire/Tertiär-Gebirge*;* Alluvial/Alluvial Gebilde*;* Volcans/Vulkane. *'Intermediate' ancient coal measures were squeezed in (in parenthesis) between the first two units, corresponding to Werner's old 'Transition' rocks.*

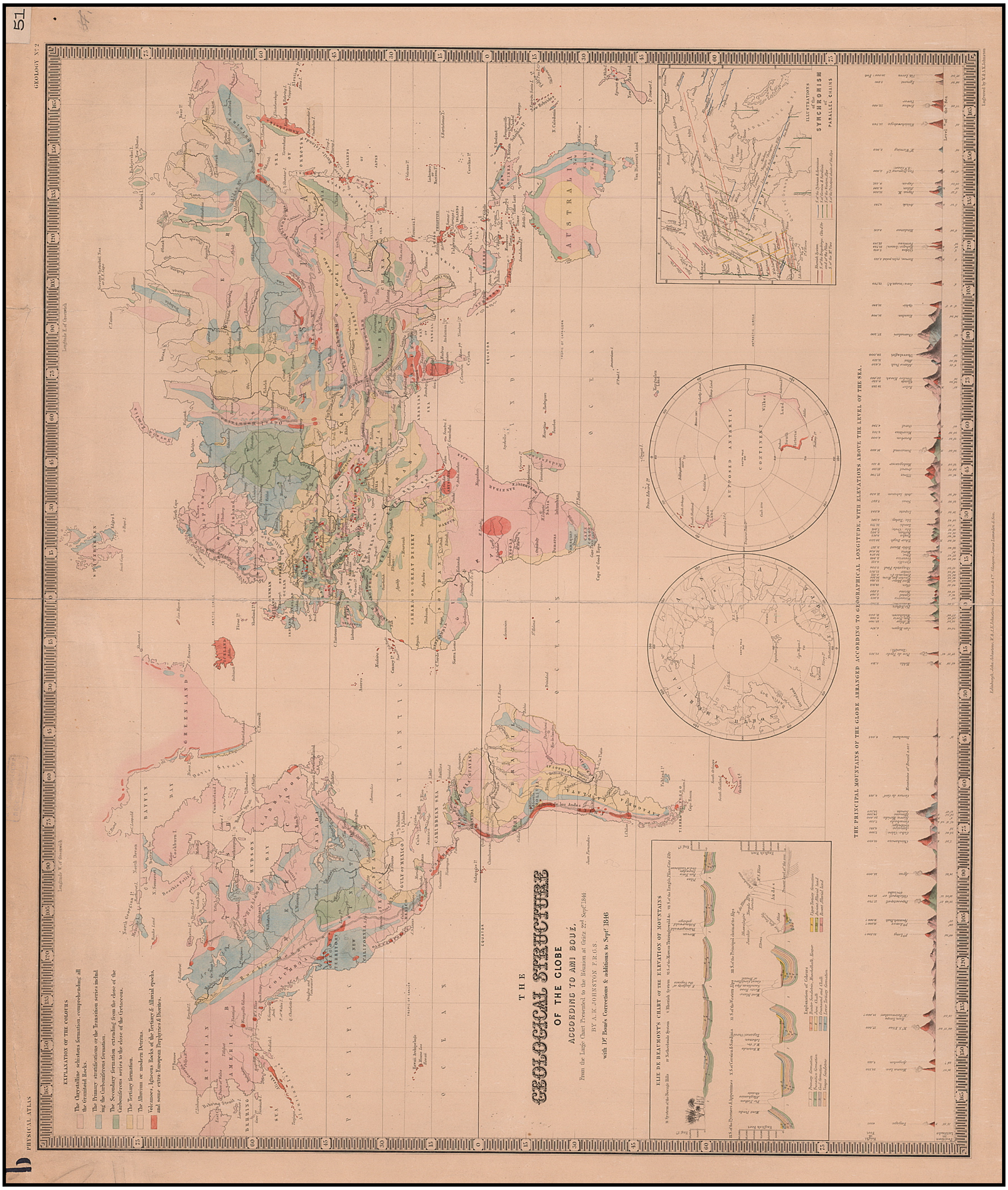

Figure 3. Boué's geological map of the world as published by A. K. Johnston (1846). Key: Pink, crystalline schistose formations and granitoid rocks; Blue, Primitive and Transition rocks including the Carboniferous; Green, Secondary formations above Carboniferous to Cretaceous; Yellow, Tertiary formations; White, Alluvium or modern detritus; Red, Volcanoes, Tertiary igneous rocks, extra-European porphyries and diorites. By courtesy of the Austrian Geological Survey (Sig. KIII 1170). The insets reveal Boué's adherence to Élie de Beaumont's tectonic theory, and the concomitant emphasis on the supposed significance of the parallelism of mountain ranges.

To explain, what sorts of geological investigations were needed and how to accomplish them in order to provide a firm basis for economic and cultural requirements, Boué again gave an extensive list of techniques that could and should be applied. Principally, he recommended the creation of mineralogical and geological maps and a thorough knowledge of geognostic circumstances in order to gain access to appropriate stones for building streets, houses and buildings possible. The locations of brown and black coal and metallic ores needed to be known. Information was needed about rivers for deciding whether water could be obtained from them or whether boreholes needed to be made to locate underground watercourses. Boué referred to Emile Puillon Boblaye (1792–1843), who had claimed that an abundance of fast-flowing water assisted the development of industry (Boué 1851a, p. 19; Boblaye 1829, p. 53). According to Boué, the location of underground watercourses was a 'lottery' as long as it was not realised that water could be found in alluvial, Tertiary and sedimentary-basin formations, as these gave rise to the main underground aquifers. He explained that water first permeates through the strata or just passes through clefts in the earth until it reaches some impermeable rock. It mostly flows in sand through more or less numerous broad channels in particular directions. However, if the layers are bent in the shape of a trough (*Trog*), or if the water descends from a hill, it will, for hydrostatic reasons, ascend as high as it had descended, as long as there are no fissures or joints or other circumstances that prevent this.

Boué also referred to medical statistics and anthropology and went on to relate physical geography and geognosy to ethnology and the history of nations, their ways of life and their forms of government. As to the influences of the Earth on human health, he claimed that certain diseases were related to certain rock types or formations, while conversely other rock types promoted human health (Verdeil 1818, Robert 1834, Robert 1845). Thus periodical fevers, typhus, phthisis (consumption or tuberculosis) and scrofula were endemic where clays prevented the infiltration and draining of rain water, as in certain areas of Weald, and the Lias and marl areas of England and France (Boué 1851a, p. 41). Struma (scrofula or goitre) and cretinism appeared to be correlated with the occurrence of talc schists[8] as well as certain dolomites (Boué 1851a, p. 42). According to the Swiss physician and politician Rudolf Schneider (1804–1880), cretinism was apparently not prevalent on Jurassic limestones in Switzerland, in contrast to the 'molasse' rocks and alluvial beds, where it occurred more frequently.[9] Schneider carried out similar comparative studies on deaf-mute and mentally ill patients (Boué 1851a, p. 42). Cholera generally avoided the high older schist formations (Boué 1851a, p. 42) but was found in dwellings in the lower areas and along large rivers. Bladder stones occurred at high frequency in chalky and Tertiary regions (Boué 1851a, p. 42). Intestinal worms mostly appeared in other regions. Boué mentioned the Guinea worm,[10] appearing only in the trap districts of Hindustan, while Switzerland offered several types of tapeworm. It could be shown that in some cases these diseases not only weakened human constitutions but also gradually developed regional characteristics. Pale faces and thin individuals were seen in generally rather weak populations, not destined to live long lives and have high fertility. Their vitality was reduced and their number of individuals was decreasing.

From such correlations Boué concluded that up to a point the special geognostic conditions and the climate of any large country modified its population both physically and mentally. Otherwise, he claimed, one would necessarily find the original types amongst peoples that had migrated into Asia and Europe more frequently than was in fact the case. As an

8 A term from the Wernerian vocabulary: essentially a schistose rock containing the soft mineral 'talc'.

9 Schneider had evidently noticed thyroid abnormalities in certain areas (due to the lack of iodine in the water). He played an important part in the regulation of water supplies in Switzerland, including the so-called 'Jura Water Connection'.

10 *Dracunculiasis*, also called 'guinea worm disease', is a parasitic infection caused by *Dracunculus medinensis*, a long and very thin roundworm. The infection begins when a person drinks stagnant water contaminated with copepods infested by the larvae of the guinea worm. Approximately a year later, the disease presents with a painful, burning sensation as the worm forms a blister, usually on a lower limb and the long worm then emerges from the body (Wikipedia). It is now found only in a few African countries.

example, Boué named the Slavic peoples, whose Russian and Czech representatives on the plains were physically different from their blood relatives in the Turkish mountains.

Boué also noticed that in Europe, where the mountain ranges mostly extend from East to West, races are separated North–South, as opposed to North America where the mountains extend from North to South and where the populations are separated East–West. This led him to the thesis (which has subsequently been advanced by Jared Diamond) that landscapes precondition political–historical processes. Alpine chains have always presented obstacles to peoples who intended to cross them and thereby extend their lands. To give examples of the routes for large migrations, Boué mentioned the plains to the south of the Urals; the Caspian Gypsy Gate to the Black Sea in Transcaucasia (Georgia and Azerbaijan); Afghanistan and the Gate of India (the Khyber Pass)**;** the gate north of Syria (between Iraq and Turkey); the one north of Adana through the Taurus Mountains in Turkey; the one in Turkey near Ikhtiman (now in Bulgaria); the Iron Gate Gorge of the Danube (between the Carpathian and Balkan mountains separating Romania and Serbia), *etc*. Moreover, Boué assigned to the structure of formations their constituents, the extent of ling (heather) valleys, their many plateaux, terraces or steps, their rivers and lakes, the structure of their forelands, *etc*., all exerting some influence on the distribution of peoples, their occupations, and their cultures.

However, Boué laid greatest emphasis on the significance of edaphic differentiation[11] in influencing peoples' ethnography, their occupations, customs and characters. So, all over the globe the life and character of a nomad were generally limited to large plains, while the mountains were settled by stock breeders and industry. Hilly and flat areas had agricultural people and large industrial buildings, while the seashores and islands were the home of navigators, fishermen, and commercial people (Weerth 1842, Kolb 1843, Klemm 1843–1847). In Tertiary areas, with few stones but ample marls and clays, houses were built of bricks, while stony and rocky areas had stone or wooden houses. These specific materials had a profound influence on the styles of architecture of different regions. Boué gave the example of Mesopotamian ruins in comparison to others (Boué 1851a, p. 53). Sculptures were predominantly found in areas with marble, alabaster, basalt, granite, syenite and trachyte, as in Egypt, Greece, Asia Minor, Italy, Mexico, Peru, *etc*. Boué also mentioned Alexander von Meyendorff's map of Russian commerce (1844), which divided that country into five regions: those with woods; those with stock breeding; those with agriculture; those with manufacturing; and those with mining. The conditions of forestry, on the other hand—its income, density and location—were of great significance for human settlement and for the development of industry and ways of life (Boué 1851a, p. 53).

Considering such matters, Boué made a significant step forward and followed up from the effects that sculpture, art, daily life, and morality exerted on human culture to the indirect influence they exerted on the legal systems of different countries (Boué 1851a, p. 54), reminding us again of Montesquieu's 'spirit of the laws'. He claimed that an area provided each country with its natural borders (Finch 1833), determined the locations of its cities, its market centres, and its capital (Reuter 1847, p. 214). Humans contest the natural constraints by wars in order to try to acquire more territory. But he declared this an evil, as revealed by a population's inevitable deterioration as the consequence of intrusions into areas contrary to its natural boundaries.

3. THE RELATION BETWEEN GEOLOGICAL AND MINERALOGICAL FORMS OF KNOWLEDGE AND THEIR APPLICATION TO MINING

Our next question concerns Boué's view of how geological and mineralogical knowledge have become and are essential to mining. To emphasise the significance of geological knowledge in the exploitation of minerals, Boué basically made three attempts at improving mining efficiency. In his publication *Ueber die Nothwendigkeit einer Reform des bergmännischen Unterrichtes in*

11 Relating to soil characteristics, rather than climatic factors.

Österreich und über den vom grossen Publikum bis jetzt oft verkannten grossen praktischen Thätigkeitskreis der Geologie (*On the Necessity of Reforming Mining Education in Austria and on the Large Field of Practical Applications in Geology*) (Boué 1869b), he suggested the inclusion of more geological theory in mining students' training programs, with the intention of improving their geological understanding. Linked to this problem, Boué asked the vexed question: *Werden der Menschheit immer, wie jetzt, Mineralschätze zu Gebote stehen?* (*Will Humanity Continue to be Provided with Mineral Resources?*) (Boué 1868). And he warned of the overexploitation of mineral resources, particularly coal and iron, the main materials needed during the period of industrialisation. Furthermore, he predicted that mining entrepreneurs would run out of these resources if due care wasn't taken. He openly disapproved of miners having maximum profits as their sole interest, neglecting reasonable and fruitful practical applications of geological knowledge in the planning of mining engineering projects. And third, miners should not disregard the geological environment when prospecting for mineral resources. Thirty years before, Kaspar Sternberg (1761–1838) had warned in his *Umrisse einer Geschichte der böhmischen Bergwerke* (Sternberg 1836–1838) of the neglect of certain mineral resources in Bohemia, particularly with the closing of silver and gold mines. Sternberg claimed that gold and silver mining could be revived by drainage of the mines in Pribram, Jachimov and Kutná Hora. To achieve this he suggested the application of steam power, which again called for the intensified use of coal. Coal was readily available in Bohemia at the time and Sternberg was himself the owner of large black coal deposits. However, an outdated mining law from 1249–1251 had prevented modernisation and it was only replaced in 1854 when it was adapted to the modern requirements of the time (Schweizer 2009, p. 337).

In 1865, the English economist William Stanley Jevons (1835–1882) had published a detailed monograph on the need for, availability, and probable exhaustion of coal (Jevons 1865), focusing on the situation in Britain. It is evident that the issue had become more urgent in England at that time than in Central Europe, where industrial development and the construction of steam engines had begun later. Boué did not refer to Jevons, but, like Boué, he started his argument by considering geological factors. He then gave an outline of the costs of coal mining and of coal itself. He also considered the costs of fuel and motive power and pointed to the importance of keeping them low. Eventually, Jevons suggested coal substitutes from agencies such as the attraction of the sun or the moon causing the tides. It is particularly interesting to find that Jevons' conclusions, though restricted to the British population and based on problems of the availability and consumption of coal, presented ideas similar to Boué's more general outline of the relationship between geology and human civilisation with respect to the growth and migration of populations. The parallelism of the thinking of Boué and Jevons indicates the way that Boué was in touch with, or leading, advanced thinking about populations, commerce, economic prosperity and the environment. In 1873, he published his essay *Ueber wenig berücksichtigte geologische Theorien zur Auffindung von rentablen Bergwerken in weit entlegenen Erdgegenden* (*On Little-Considered Geological Theories in the Finding of Profitable Mines in Remote Areas of the Globe*), in which he extended the question of mineral exploitation and mining efficiency to the global scale.

Boué's contacts with Haüy, Weiß, Mohs and Zippe as the leading mineralogists of their time have been mentioned above. The appearance of these names in his bibliographical data evidence Boué's high estimation of mineralogical knowledge and its development. In the introduction to his *Der ganze Zweck und hohe Nutzen der Geologie* he represented crystallographic and chemical mineralogy, as well as physical geography in its widest sense, as providing the fundamentals of geology.[12] "Nowadays", he wrote, "there are five parts distinguished in geology, one of which, *i.e.* petrology, equates with the mineralogical and chemical knowledge of rock species" (Boué 1851a, p. iv).[13] The other term "geographic

[12] Interestingly, stratigraphy was not mentioned, illustrating Boué's German background.

[13] In der Geologie unterscheidet man jetzt gewöhnlich fünf Theile namentlich, die P e t r a l o g i e [sic!] oder mineralogisch-chemische Kentniss der Gebrirgsarten.

geology" referred to topographic mineralogy and geology (Boué 1851a, p. iv). Geognosy or theoretical geology "predominantly [consists] in finding the most probable explanation for the formation of each mineral, each ore, and each rock species" (Boué 1851a, p. v).[14] So Boué related virtually all higher-order formations and rock types to their mineral composition. He documented this view in great detail in his essay *Über die mineralogisch-paläontologische Bestimmung der Formationen mit Beispielen ihrer Anwendung, um die Geologie des Erdballes zu erfassen* ('On the mineralogical–paleontological determination of geological formations, including examples of its application in analysing the geology of the globe') (Boué 1865).

It should be noted that by 1851 Boué had given up Mohs' strict conventionalism, regarding minerals as merely crystallographic entities with specific crystallographic parameters without considering their chemical composition. To ensure the efficient exploitation of minerals, Boué emphasised in *Der ganze Zweck und hohe Nutzen der Geologie* the importance of investigating geological dykes, since minerals often appear dissolved in water percolating through the dykes, while being gradually 'salted out'. Technically, Boué recommended prospecting and drilling for minerals such as salt, coal, and metallic ore bodies. For the drilling operations he regarded detailed knowledge of geology as an absolute necessity. It was obsolete and irresponsible just to drill into the ground without knowing, from the course of dykes, where minerals might have 'salted out'. Similarly, new water sources should be located on the basis of scientific principles.

Boué's paper *Ueber wenig berücksichtigte Theorien* is a telling example of the impact and accuracy of his scientific approach as regards the *detection* of mineral deposits. He referred to the work of Klaus Schmidt,[15] published as early as 1821, and pointed to the fact that mineral resources can either be restricted to dykes or may appear in layered deposits, so that the dykes and layers crossing each other in different directions form a complex network emerging from joints and fractures (Schmidt 1821, pp. 9–10; Boué 1873, p. 3). But even more importantly he maintained that metal-rich veins appear in parallel with long rocky crests, and that the relative age of the principal dykes and veins and even their inclination could be determined according to Werner's theory of veins (Werner 1791, 1809), that dykes of the same age usually run in parallel, and that dykes as well as many metal deposits follow the same directions as those of certain plutonic or eruptive masses, as well as many mineral waters, while major earthquakes also follow the same directions, or at least are parallel to the dykes and the metallic deposits (Boué 1873, pp. 3–4).

However, according to Boué these correlations have not always been the same, but have differed greatly over time. Thus the nature of eruptive masses as well as mineral waters changes, in particular regarding the latter's quantity, while great changes can also be assumed with regard to earthquakes. Thus their dynamic results may also have been modified over time. He concluded that "[i]t is comprehensible how different those metal deposits, connected to the older porphyries or to trachytes and rhyolites are now, and even how different their dyke masses are"[16] (Boué 1873a, p. 4). Once familiar with these relations, and regarding the indications of ores in all countries, Boué recognised that ore deposits follow certain lines and are not randomly distributed. He continued to consider the fractures in the Earth's crust, which allowed the escape of heat from the Earth's interior. Such movements would even move the heavy metals, though they are not apt to sublime, into the clefts, where they would be retained. These considerations led him to conclude that certain ores were associated with certain eruptive rock species. And so specific minerals seemed to be associated with specific rocks and/or other specific minerals. On the basis of such geognostic facts, Boué developed a whole catalogue of correlations (Boué

14 . . . besteht nicht nur in allgemeinen Systemen, sondern vorzüglich in den Versuchen die w a h r s c h e i n l i c h s t e E r k l ä r u n g ü b e r d i e B i l d u n g j e d e s M i n e r a l s , j e d e s E r z e s, j e d e r G e b i r g s a r t u n d j e d e r F o r m a t i o n a u s z u m i t t e l n.

15 Klaus Schmidt was in fact Johann Christian Leb(e)recht Schmidt (1778–*ca* 1830), counselor of mines and Director of the mining school at Siegen (Germany) (Fischer 1961, p. 352).

16 *Es ist sattsam bekannt, wie die mit älteren Porphyren oder die mit Trachyten oder Rhyoliten verbundenen Metallschätze verschiedener Natur uns selbst wie verschieden ihre Gangmassen sind.*

1873, pp. 8–10), seemingly verified by the occurrence of particular groups of associated minerals, such as:

> Tin, molybdenum, scheelite (tungstan), tantalum, uranium, cerium and antimony seem to be particularly associated with granite.
> Titanium and zirconium are particularly associated with syenites, and titanium with iron.
> Gold is often connected with trachytes and porphyry, while veins with gold most often consist of quartz.
> Manganese and particularly silver are associated with porphyry.
> Silver is often associated with lead, and rarely with selenium, mercury and antimony.
> Mercury penetrates the Earth's crust through trachyte eruptions.
> Platinum, palladium, osmium, iridium, and chromium/iron occur in serpentines.
> Copper, lead and zinc are commonly associated with trap (basalt), and are often near calcareous rocks.
> Nickel occurs in small amounts, but forms an ore with arsenic and iron.
> 'Sulphurous cobalt', a workable ore that only occurs in the older schist formations.

Presumably, Boué based this list on the available literature on the topic, for he did not mention the sources from which he had drawn his information. But it would have been fairly common knowledge in mining lore at the time.

Another approach linking geology to mineralogy was outlined in Boué's article *Über die mikroskopische Untersuchung der Gebirgsarten mit Hilfe ihrer mechanischen Zerreibung, partiellen Schleifung und Ätzung* ('On the microscopic examination of rock types by mechanical trituration, partial grinding and etching') (Boué 1863). He went back to work done in 1816, when the French mining engineer Louis Cordier (1777–1861) published his technique for the mechanical triturating and microscopic examination of volcanic and plutonic rock specimens, trying to find evidence to settle the question of whether basalts were of igneous or aqueous origin (Cordier 1816; Boué 1851a, p. 466; 1863, p. 1)—which work had emerged from two earlier articles on the examination of volcanic products, particularly iron sands (Cordier 1807, 1808). The use of the microscope for studying thin sections was developed in the course of the nineteenth century, especially in the work of Henry Clifton Sorby (1826–1908), who investigated the structure of calcareous grit (Sorby 1851) and the composition of calcareous marls and limestones from Tertiary strata in Britain (Sorby 1853). As is well known, this microscopical approach to rock composition subsequently became an important step forward in the examination of the mineral composition of rocks.

4. CONCLUDING REMARKS

In his essay *Über die ewigen Gesetze der Natur* ('On the constancy of the laws of nature') Boué (1851b) explicitly affirmed his position on this question, which determined his approach to research. He insisted on the importance of recognising the connections between the individual scientific disciplines, all linked, co-working, and interacting with each other, in order to obtain answers to relevant structural, economic and cultural questions. He disapproved of boundaries between disciplines. His concept of eternal laws, effecting Nature in the most simple and self-evident way, is reminiscent of Spinoza's and Goethe's approach to science (Schweizer 2007), with Spinoza's basic rule of *Deus sive natura*.[17] Moreover, throughout his career Boué observed the economic needs and the cultural problems associated with the Industrial Revolution, which started in Britain at the end of the eighteenth century and rapidly spread all over Western Europe, North America and eventually much of the world. The demand for mineral resources increased and with their growing exploitation the question arose as to whether there would be sufficient raw materials for future industrial developments. Production in industrial centres

[17] Paraphrase: there is no distinction between the Creator and Creation.

required rapid transport facilities. The invention of the steam engine made relatively rapid transport possible, but at the same time necessitated a greatly increased use of iron and coal. In response to industrial progress, the social and economic structure of the population changed and in consequence so too did cultures. Boué recognised the significance of geographical and geological contexts and found in the application of geological research and its results possibilities for bridging the gap between industrial and economic necessities on the one hand and excessive demands on resources and changing sociological conditions on the other. His thinking not only transcended the boundaries of geological science: it also transcended continents as he tried to find general geological answers to questions about the structure and constitution of the globe (Boué 1865). This approach was linked to his holistic view of industrialisation and its relation to geology.

However, given Boué's broad synoptic view of the requirements of his time, it is surprising to find that he based many of his geological views on somewhat outmoded theory, as for example when he based the determination of the age and inclination of dykes in geological formations on Werner's theory of veins of 1791. It also appeared in his deployment of Cordier's technique of mechanical triturating and microscopic examination of volcanic and plutonic rock species, which went back to 1808. As regards Wernerian ideas, it shows that they were still influential in the German-speaking parts of Europe in the mid-nineteenth century. It may be noted that Werner himself famously impressed the significance of geognostic factors on life and culture, and Jameson would likewise have emphasised such matters in the lectures that Boué attended in Edinburgh.

Recalling Boué's attempts to explain a vast field of effects in our cultural, economical and political world by geo-scientific research, we may regard him as a leading, broadly-oriented scientist, linking not only geological theory to its practice but also to other scientific disciplines, particularly mineralogy, and to their impact on general human conditions and wellbeing. But, as said, it appears that he based his geological approach on views that had emerged a long time before he made his own first geological investigations, and in this respect he differed greatly from modern geologists.

That Boué's attitude to science in general, and geology in particular, approached the borders of metaphysics is demonstrated by his statement in the last chapter of *Der ganze Zweck und der hohe Nutzen der Geologie*:

> The geologist, like the scientist and astronomer, cannot by any means find any end to his admiration of our beautiful laws and the composition of Nature, which characterises all—the almost invisible as well as the largest—in an almighty and unique way. This fact gave rise to those innumerable works on so-called natural theology, as by Derham (1720), Lesser (1740–44),[18] Paley (1819), Vivian, Whewell, *etc*., as well as those nine extraordinarily interesting Bridgewater Treatises (1833–1834) and Grube's biographies from natural history. The c u l t u r e o f s c i e n c e i s a r e l i g i o u s p r a c t i c e and the whole of existence lies in the reign of reason, as Confucius recognised and as the late Oerstedt beautifully outlined in his *Geist der Natur*[19] (1851a, pp. 119–120).

Hans Christian Oersted (1771–1851), the Danish physicist and Nature Philosopher, strongly influenced by the scientific position of German Romanticism, certainly exhibited a different approach to science from that of Boué, but they obviously both regarded Nature as

18 Boué was referring here to the second and subsequent editions of Lesser's *Insectotheologia*, first published in 1738.

19 Der Geolog so wie der Naturforscher und Astronom kann gar nicht aus seiner Bewunderung der schönen Naturgesetze und Einrichtungen herauskommen, die Alles, das Unsichtbarste wie das größte allmächtig und einzig charakterisirt. Dieses gab besonders Anlass zu jenen zahlreichen Werken über die sogenannte natürliche Theologie, wie die von Derham (1720), Lesser (1738), Paley (1819), Vivian, Whewhell u. s. w. So wie zu den neun äusserst interessanten Bridgewater Treatises (1833–1834) und zu Grube's Biographien aus der Naturkunde 1850. Ueberhaupt ist die C u l t u r d e r W i s s e n s c h a f t n u r e i n e R e l i g i o n s ü b u n g und das ganze Dasein ein Vernunftreich wie Confucius es schon auffasste und wie der selige Oerstedt es sehr schön in seinem *Geist der Natur* (1850) aueinandersetzte.

divine—though Boué may have drawn that view from Nature's existence as a "reign of reason" rather than from the assumption of some unknown God acting in some inscrutable way. Boué's words make fairly obvious that in his view the priests of Nature were not the Biblical scholars but scientists. Nature was a divine entity, to be maintained and respected by scientific endeavours. In other words science, for Boué, was a kind of religious practice.

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