The voyage of the ‘Guyot Stone’ from the Swiss Alps to Neuchâtel and Princeton

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Abstract

In 1890, former students of Arnold Guyot at the University of Neuchâtel dedicated a ‘large glacial boulder from Neuchâtel’ to his memory, now in front of Guyot Hall at Princeton University. We established that this block originated with all certainty from Upper Carboniferous conglomerates of the Salvan–Dorénaz Basin, the relics of which crop out in the Alps of western Switzerland and eastern France. During the Last Glacial Maximum, the boulder travelled from the lower Rhône Valley on the back of the Pleistocene Rhône Glacier to Neuchâtel from where, later, it crossed the Atlantic and was transported to Princeton. Guyot’s name is familiar to geologists because of the term ‘guyot’, introduced 1946 by Harry Hess for ‘curious flat-topped peaks scattered over millions of square miles in the Pacific basin’, many of which are now known to represent drowned carbonate platforms.

Keywords Arnold Guyot · Guyot Stone · Vallorcine Conglomerate · Upper Carboniferous · Salvan–Dorénaz Basin · Rhône Glacier · Pacific seamounts

Introduction

In the early nineteenth century, the town of Neuchâtel in western Switzerland was a hotbed of geological activity with Louis Agassiz, Amann Gressly (who coined the term ‘facies’) and a few other young scientists of the Academy of Neuchâtel that included a young man, Arnold Guyot. Louis Agassiz was the *chef de file* of this group. At an early stage, he had earned broad recognition with his studies on fossil fish and later even more so by propagating the Ice Age Theory of Ignatz Venetz and Jean de Charpentier, for which *he* received all the credit, much to de Charpentier’s irritation.

Until 1848, the sovereign of Neuchâtel was the Hohenzollern King of Prussia, a circumstance that led to a curious

situation whereby Neuchâtel was at the same time, a Prussian *principauté* and a Swiss Canton after 1815, the year Neuchâtel became part of Switzerland during the Congress of Vienna. This strange situation came to an end with the anti-aristocratic revolution of 1848 when the Canton de Neuchâtel was integrated into the modern Swiss Confederation and Neuchâtel became a republic. Finally, the King of Prussia gave up his rights in 1857. As a consequence of the revolution, the Academy in Neuchâtel was closed and most members who belonged to the privileged pro-Prussian fraction of the town left the city. Louis Agassiz had emigrated already in 1847 to the United States and Arnold Guyot, who remained a lifelong friend and companion, followed in 1848. Agassiz’ self-assured and ambitious character was probably one of the reasons that the group disbanded. Agassiz became one of Harvard’s most popular professors and one of the most influential naturalists of America; however, he never escaped from his fundamental beliefs rooted in a strong protestant education, leading to a strange mixture of science and Christian theology culminating in his fight against Darwin’s Theory of Evolution. His openly racist views are widely discredited today.

To the memory of Jean-Paul Schaer (1928–2021).

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Arnold Guyot

Arnold Guyot's biography is summarized in papers by Schaer (1988), and Wilson (1999), and two concise brochures written for the Department of Geosciences at Princeton University (Koelsch 2007; Wilson 2007). Guyot (Fig. 1) was born 1807 in Boudevilliers (Neuchâtel). After completing his studies in La Chaux-de-Fonds and at the Collège de Neuchâtel, he spent several years near Karlsruhe (southern Germany) where he met other young scientists, most prominently Louis Agassiz. In 1829, he enrolled at the Friedrich Wilhelm University in Berlin where he followed a wide spectrum of classes from theology and philosophy to the natural sciences. Most determining for his scientific development were the mentorship of the geographer Carl Ritter and the influence of the work of the great Alexander von Humboldt. After defending his Ph.D. thesis on 'The Natural Classification of Lakes' in 1835, Guyot worked as a private tutor for an aristocratic family in Paris. At that time, this was often the first step in the career of a young scientist.

At the founding of the Academy of Neuchâtel in 1839, Guyot was appointed Professor of Physical Geography and Universal History by the Prussian authorities. He worked mainly alongside Agassiz on glacial formations and laid the foundations for his later research and teaching in the United States. His 1849 lectures in Boston on 'Comparable Physical Geography' resulted in a popular book *Earth*

and *Man* that popularized Alexander von Humboldt's geo-historical views, and paved his way to a Professorship of Physical Geography and Geology at the College of New Jersey that later became Princeton University. He held this position from 1854 until his death in 1884. Guyot saw the Earth like Hutton as a living organism in which nature and mankind interacted harmoniously according to Divine guidance. In his entire work and in his last book, '*Creation or The Biblical Cosmogony in the Light of Modern Science*' he aimed at reconciling science and religion. Unlike Agassiz, who was a rigorous creationist *avant la lettre*, he finally believed in limited evolution, but within a teleological context and without accepting Darwin's idea of natural selection.

To honour the memory of Guyot, Princeton University named its new building for Biology and Geology 'The Guyot Hall' (1909). In 1890, 6 years after Guyot's death, his former students at the University of Neuchâtel dedicated a large 'glacial boulder from Neuchâtel' to his memory, the Guyot Stone, originally placed at the entrance of Nassau Hall, residing now outside Guyot Hall (Fig. 2a). The inscription reads: 'Glacial boulder from Neuchâtel, Switzerland, presented 1890 in memory of Arnold Guyot, Professor of Geology at Princeton 1854–1884 by his former students at the University of Neuchâtel'. A plaque with the portrait of Guyot was mounted on a slab of the Guyot Stone and installed in the old Marquand Chapel of the university (Coye 2009).

Fig. 1 Arnold Guyot 1807–1884

The Guyot Stone and its provenance

For the origin of the Guyot Stone, we have to turn away from Neuchâtel, the area where Guyot's former students recovered the large erratic boulder, and direct our attention to the Alps, to an area about 100 km to the south (see Figs. 3, 5 below). Outcrops of identical facies and composition to the Guyot Stone (Fig. 2) are found in the Upper Carboniferous Vallorcine Conglomerate and the related Dorénaz Conglomerate of the Mont Blanc area of the Western Alps that during the Pleistocene was covered by the Rhône Glacier. The clast spectrum of the Guyot Stone and the Vallorcine Conglomerate are clearly distinct from that of other conglomerates outcropping in the reaches of the Rhône Glacier. In contrast to conglomerates from Cretaceous flysch formations or from the Cenozoic foreland deposits of the Swiss Molasse Basin, the Guyot Stone and the Vallorcine Conglomerate are devoid of clasts of Mesozoic dolomites or limestones, or ophiolites, but include exclusively clasts of Variscan basement rocks or of syn-sedimentary volcanics.

The similarity of the Guyot Stone (Fig. 2a) and the conglomerate illustrated in Fig. 2b is compelling. Both conglomerates include subrounded pebbles and smaller lithic fragments in a sandy matrix. Most conspicuous are the

Fig. 2 **a** The Guyot Stone at the entrance of Nassau Hall, Princeton University, 1970s; The stone is about 142 cm wide and 109 cm tall. The original inscription is no longer preserved but has been replaced by a bronze plate. **b** Vallorcine Conglomerate of the Salvan–Dorénaz Basin, showing facies, texture and composition identical with the Guyot Stone. Characteristic of both are the angular black shale pebbles, the angular to subrounded clasts of magmatic and metamorphic basement rocks, and the abundance of muscovite and biotite flakes. Outcrop located on the right bank of the Rhône valley near the village of Dorénaz in the proximity of the rock-climbing wall of Escalade Rond Point. Hammer for scale is about 32 cm long

occurrence of angular black shale pebbles, angular to subrounded clasts from magmatic and metamorphic basement sources, and the abundance of muscovite and biotite flakes dispersed in the sandy matrix.

The conglomerates are part of the Vernayaz Formation (= Salvan–Dorénaz Fm.), a loosely defined term for the basin fill of the Late Carboniferous Salvan–Dorénaz sedimentary basin, the relics of which extend for about 25 km along the south-eastern margin of the Aiguilles-Rouges Massif (Fig. 3), across the border between Switzerland and France. Today, the remnants of this basin crop out in a NE–SW-trending complex syncline formed during the Alpine Orogeny (Fig. 4). The basin evolved in a continental,

intra-mountainous and tectonically controlled setting with the sediments derived from the rapid erosion of granitic, volcanic, low- and high-grade metamorphic, and limited sedimentary terrains involved in the Variscan Orogeny (Capuzzo et al. 2003).

The stratigraphic sequence of the Salvan–Dorénaz Basin is about 1.5–1.7 km thick. It comprises a dominantly conglomeratic, basal alluvial fan unit, where facies equivalents to the Guyot Stone are common (Fig. 2b), that is overlain by sediments deposited by an evolving fluvial and flood plain system, interfingering locally with alluvial fans derived from the basin margins (Capuzzo and Wetzel 2004).

The lower alluvial fan Unit I of the Vernayaz Formation can be equated to the classical Vallorcine Conglomerate, from where the Guyot Stone most likely started its long journey. It comprises prevalently massive to crudely stratified, poorly sorted, texturally and compositionally immature and well-cemented conglomerates, pebbly sandstones, and lithic, arkosic to feldspathic arenites and greywackes. In thin-section, sandstones show a clast- to matrix-supported fabric with angular to subrounded grains, with detrital grains principally composed by mono-crystalline and poly-crystalline quartz, feldspar, mica flakes, and lithic fragments. Elongated black shale intraclasts of variable sizes are common, often plastically deformed into pseudo-matrix. Lithic fragments are abundant and prevalent in the coarser grain sizes; they mainly comprise plutonic/gneissic rocks, micaschists, and acidic volcanic fragments, denoting provenance mainly from magmatic and metamorphic sources. In addition, minor amounts of meta-sedimentary rocks are observed. Characteristically, abundant mica occurs as large detrital flakes with relatively elongated shapes, in places concentrated along laminae, with muscovite normally more abundant than biotite.

Initially, the Late Carboniferous age of these rocks was determined from macrofloral associations that were mostly identified in the organic-rich black shales of the alluvial-plain facies associations. Their Westphalian D to Stephanian A age (Jongmans 1960) is in line with more recent U/Pb radiometric age determination on zircons from volcanic flows at the base, and from several tuff layers observed at various stratigraphic intervals (Capuzzo and Bussy 2000). These radiometric ages indicate that the basin evolved between 308 ± 3 Ma and $295 \pm 3/4$ Ma from about Barruelian (Kasimovian, beginning at 307.3 ± 0.1 Ma) to Asselian (beginning at 298 ± 0.15 Ma) time. Its formation is related to post-Variscan rifting, accompanied by granitic intrusions and volcanicity as observed ubiquitously in the European crust (e.g. Ziegler 1990 and Fig. 4).

During the Alpine Orogeny, the sediments of the Salvan–Dorénaz Basin were intensely deformed under high anchizonal (sub-greenschist facies, < 300 °C) conditions (Pilloud 1991), and the originally horizontal strata often rotated into vertical position (Fig. 4). In 1796, Horace Bénédict de

Fig. 3 Tectonic sketch-map of the Rhône Valley area. Tectonic units: AR Aiguilles Rouges Massif, H Helvetic nappes, MB Mont Blanc Massif, SF Subalpine Flysch, SM Subalpine Molasse, UH Ultrahelvetetic nappes, Localities: D Dorénaz, M Martigny, S Salvan, V Vallorcine, black: Carboniferous sediments of the Aiguilles Rouges Massif (Dorénaz–Salvan Basin)

Fig. 4 Cross-section across the Salvan–Dorénaz Syncline and the Dents de Morcles. From Badoux (1971)

Saussure (1740–1799), a geologist and natural scientist from Geneva, carefully described in his book ‘*Voyages dans les Alpes*’ his field observations on the ‘Poudingues de Valorsine’ (1786, Chapter XX, pp. 98–107) and, recognizing that they were originally deposited as horizontal strata, invoked an ‘unknown revolution’ following their lithification as the cause for their vertical or steeply dipping orientation. Because the associated rocks (gneisses, schists) show a parallel steep dip, the entire rock pile had to be dislocated to form the mountains that include the sediments of an ‘ancient ocean’ (de Saussure 1786: 103–104). Like Werner and many geologists of his school, de Saussure regarded granite and gneiss as sediments of the primordial ocean, but he clearly recognized the stepwise growth of the Alps from the interior, exposing the primary, steeply dipping rocks, to their margins with more gently dipping secondary rocks that were involved not only in vertical uplift but in lateral thrusts. De Saussure’s observations on the nature of rocks, erosional, and sedimentary processes, and his studies on fossils also led him to believe that the Earth had to be much older than generally thought at his time (Carozzi 1989).

The voyage from the Alps to Neuchâtel and Princeton

The discovery of blocks and boulders exotic to the Jura Mountains of Neuchâtel played a major role in the formulation of the Theory of the Ice Ages by Agassiz (1840) and de Charpentier (1841) (Krüger 2008), allowing the mapping of the extension of the Alpine glaciers. In addition, characteristic lithologies of many of the erratic blocks provided information on the source area of the glacial materials (e.g. Guyot 1847). Many of the erratic blocks of the Neuchâtel

area could be related to source areas in the upper reaches of the Rhône valley and in the area of the Mont Blanc Massif.

The extension of the Rhône Glacier during the Ice Ages was already known at Guyot's time as illustrated in the map of de Charpentier (1841). The Rhône Valley was, during the Last Glacial Maximum (LGM, ~24,000 y BP), one of the major outlets of ice from the Alps. The flow of the ice to the foreland was confined by the Jura Mountains in the north-west and divided into two distributary systems directed to the northeast (Solothurn Lobe) and to the southwest (Geneva Basin) (Schluchter 2009; our Fig. 5). Most of the vestiges of the glaciations preceding the LGM were erased during the LGM, or were covered by the deposits of the LGM, and the erratic blocks within the area affected by the LGM can be attributed with some certainty to it (Jouvet et al. 2017).

The ice flow of the Rhône Glacier during the LGM must have been complex: many erratic boulders with lithologies characteristic for the higher Pennine and Austroalpine nappes or of the Mt. Blanc and Aiguilles-Rouges Massifs situated on the south (left-hand) side of the Rhône valley are found on the Solothurn Lobe, the right distributary arm of the Rhône Glacier, i.e. the opposite side of the glacier (Kelly et al. 2004; Jouvet et al. 2017; Fig. 1). Glacial boulders must therefore have been transported across the glacier from the left to the right valley side and into the Solothurn Lobe that occupied the Neuchâtel area (Schluchter 2009). Such a transport route is compatible with an origin of the Guyot Stone from the Mont Blanc-Aiguilles Rouges region: indeed, lithologies from this area, including the Vallorcine Conglomerate, are abundant on both sides of the Solothurn lobe (Kelly et al. 2004). According to Gilliéron (1885: 438) most of the blocks larger than 1 m³ derived from the Valais area are from facies similar to the 'Poudingue de Vallorcine', which are part of the Upper Carboniferous conglomerates of the Salvan–Dorénaz Basin.

The voyage of the Guyot Stone from Neuchâtel to Princeton cannot be reconstructed in detail. We only know that the transport was financed by a public subscription in Neuchâtel and occurred between 1888 and 1890 and that the stone was installed with a ceremony on June 10, 1890 (Coye 2009).

Guyot's heritage

While in Switzerland, Guyot's contributions to geology were mainly in the fields of limnology and glaciology and as he later claimed, his stay in Neuchâtel, at the side of Agassiz, was the most active period in his life. However, his professorship in Princeton, the first of its kind in Physical Geography and Geology in the United States, was highly influential in establishing geology as a science in both academia and professional practice. The focus of his work was now 'the educational use of science to illuminate God's handiwork in

Fig. 5 Extension of the Rhône Glacier during the Last Glacial Maximum (LGM) with the locations of Dorénaz, Salvan, Vallorcine, and Neuchâtel. After Schluchter (2009), Source: Swiss Federal Office of Topography Swisstopo, Bern

the creation of ordering of the universe' (Wilson 2007). In the United States, his major accomplishments were establishing a system of weather stations, introducing new methods of geography education, and creating a series of geography textbooks and teaching aids, and the creation of a large collection of geological and palaeontological specimens at Princeton (Wilson 1999).

Guyot's name is familiar to geologists because of the term 'guyot'. The term was introduced by Harry Hess in honour of Guyot, for 'curious flat-topped peaks scattered over millions of square miles in the Pacific basin' (Fig. 6; Hess 1946: 772).¹ During World War II, Hess had spent 2 years at sea in the western Pacific on board U.S.S. Cape Johnson recording randomly the bathymetry along the track of the ship. Hess (1946) interpreted his guyots as sunken erosion-truncated volcanic

¹ Arnold Guyot was not the only person of Agassiz's group that emigrated to the United States whose name is associated with marine geology. Louis François de Pourtalès (1823–1880) emigrated like Agassiz in 1847 and joined the US Coast Survey where he studied the reefs of Florida, the Bahamas and the Antilles, and deep-water corals and sediments in the seaways between the carbonate platforms. The Pourtalès Terrace, a submarine terrace, exposing Eocene to Miocene carbonate rocks sealed by phosphatic hardgrounds and deep-water coral reefs offshore the east-Florida Coast and the Florida Keys, was named in his honour.

Fig. 6 Illustration of a typical guyot by Hess (1946: Fig. 2). **a** Fathometer recorder trace of a typical guyot **b** Diagram traced directly from Fig. 6a with adjustments for steep slopes

islands rising to about 3000 m from the ocean floor to a water depth of between 1000 and 2000 m. Before his conversion to continental drift and sea-floor spreading (Hess 1962), Hess believed in the permanence of continents and oceans (Hess 1954), and the Pacific Ocean and its guyots to be Precambrian in age (Hess 1946).

In 1950, an expedition of the Scripps Institution of Oceanography and the US Navy Electronics Laboratory found that the ‘sunken islands of the Mid-Pacific Mountains are a great submarine mountain chain ... surmounted by sharp peaks and ridges and by anomalous flat-topped guyots ... [extending for] a distance of about 1500 nautical miles’ (Hamilton 1956: 4–5). Within the frame of plate tectonics, the linear volcanic seamount chains with their time-transgressive evolution can now be interpreted as trails of volcanoes on the ocean floor left by hot spots, thermal plumes from the deep mantle affecting the Pacific Plate as it migrated across them (Wilson 1963: Fig. 5; Morgan 1971, 1972; Jackson et al. 1980).

At first, Hess (1946) speculated that guyots were drowned atolls, but discarded this idea as untenable, because the seamounts did not show the steep slopes typical for atolls, and

no reefal morphologies or limestones that would testify to carbonate build-ups were known from the seamounts at that time. However, dredging by the 1950 expedition on the Mid-Pacific Mountains brought to light ‘middle’ Cretaceous (Aptian–Turonian) reef-building hexacorals and rudist bivalves typical of carbonate platforms and, up-section, Upper Cretaceous to Cenozoic pelagic ooze and chalk with planktonic Foraminifera, in part phosphatized and yielding manganese nodules testifying to episodic non-deposition and early submarine diagenesis (Hamilton 1956; Matthews et al. 1974). Ever since, dredge hauls and deep-sea drilling have shown that the volcanic underpinnings of the seamounts are typically overlain by a deepening-upward succession of shallow-water and pelagic sediments (Premoli Silva et al. 1993; Winterer et al. 1995). The flat top of guyots is not related to erosion, as assumed by Hess (1946), but reflects the depositional geometry of the shallow-water carbonate platforms whose sediments were always deposited close to sea level, a geometry inherited after the systems drowned and were mantled with pelagic sediment. This stratigraphic evolution places guyots into Darwin’s (1839, 1842) evolutionary sequence of subsiding

Fig. 7 The evolution of reefs from barrier and fringing reefs to atolls and guyots. From Figs. 4 to 5 of Darwin (1842) with addition of the guyot stage

volcanic islands, fringed by coral reefs, as the final stage of their history from atolls to seamounts (Fig. 7). Drowning of the Pacific atolls to sub-photic depth occurred at different times as they moved from low latitudes of tropical carbonate production, where sedimentation was not paced out by subsidence, to higher latitudes (Emperor Seamount Chain, Jackson et al. 1980), or as they migrated across the equatorial zone during Cretaceous or Eocene greenhouse intervals when environmental conditions, such as high temperatures and/or equatorial upwelling of CO₂-rich water, were unfavourable for coral or rudist growth ('Death in the Tropics', Wilson et al. 1998; Jenkyns and Wilson 1999).

There lies a slight irony in the fact that the sunken atolls of the Pacific, the last step of evolution of Darwin's coral reefs, were named after Guyot who did not accept Darwin's Theory of Evolution. We do not know whether Harry Hess, who eventually held Guyot's chair from 1964 to 1969, was conscious of this; however, his wry humour (Buddington 1969) would be in line with it.²

² During the course of writing this paper, we learned that Guyot Hall will become the home of a new Computer Science Department, and will be renamed the 'Schmidt Hall'. We hope our paper will stimulate some curiosity in the history of the far-travelled boulder, and that the Guyot Stone will find an appropriate location in the Geoscience Department at Princeton.

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