La Pierre-à-bot: a celebrity glacial erratic in the Swiss Jura and the 'Glacial Theory' in Britain

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Abstract: This spectacular mega erratic at Neuchâtel attracted many of the leading nineteenth-century British geologists who visited Switzerland. It was just one of numerous erratics on the Jura east facing slope. Its fascination revolved around the problem of how clasts of Mont Blanc granite sourced *c.*100 km away came to lie on Jurassic limestone bedrock. Initially, concepts of catastrophic debacles sweeping the erratics and later ice-berg rafting were invoked. The first recorded British observer was John Playfair who was soon followed by Henry De la Beche. In the 1830s several Swiss geologists posited that a former huge expansion of the current Alpine glaciers was responsible for the transport of the erratics. The intervention of one of these investigators, Louis Agassiz, led to the popularisation of the glacial theory (land ice hypothesis) and its introduction into Britain in 1840 with the support of William Buckland of Oxford. At first the new hypothesis was rejected by the majority of British geologists but through the work of Andrew Ramsay, who was able to draw on his Swiss field work, the terrestrial glaciation concept became progressively accepted in Britain from 1862 onwards.

Glacial erratics are rock fragments which are normally 'foreign' to the substrates upon which they are found. The name erratic is derived from the Latin *errare* – to wander. In German they are called findlinge, i.e. 'homeless children'. They show a huge range in size from pebbles to mega boulders and may occur as isolated clasts or be incorporated within tills and gravels. Since they have been transported by ice to their current locations their composition reflects the bedrock geology over which the eroding glacier has flowed. A range of ages may be involved, from Neoglacial fluctuations within the Holocene to those associated with the major glacier stages of the Pleistocene. In Britain Harmer's (1928) classic study of erratic and drift distribution in England and Wales led to the identification of ice flow pathways and the outer limits of glaciation. Arguably the finest display of erratics in England is at Norber on the southern slope of Ingleborough in the Yorkshire Dales (Waltham 2007). A recent reactivation of interest is the 'Birmingham Erratic Boulders' project (Hereford & Worcester Heritage Trust) resulting in eight new trail guides. A contemporary debate concerns the origin and significance of the so-called 'Bluestones' which form part of the Neolithic Stonehenge monument on Salisbury Plain. All are agreed that they are erratic in their present location and are largely provenanced from Pembrokeshire but whether they are true glacial erratics or artefacts resulting from human activity is an issue yet to be resolved.

The Pierre-à-Bot glacial erratic

This giant granitic glacial erratic is a well-known element of the local landscape at Neuchâtel in western Switzerland and even gives its name to a road from which a footpath leads to its main access point (Fig. 1). Locally it is also known as Pierre Crapaud or 'toad stone' due to its crouching toad-like profile. 'Bot' is a local dialect word for a toad. It is situated in a strip of woodland close to the edge of the urban area, just a 300 m walk from an intra-urban bus stop (Trois-Chenes). Unfortunately, its visual impact is much reduced by the surrounding trees and is best viewed in winter. The disposition of the rock is unusual in that the upper surface dips at *c*. 40° giving the impression of instability, yet it has endured for some 20 ka BP (Figs. 2 & 3). The angularity and slab-like shape has struck observers from the beginning, and this is strongly suggestive that it had originated as a rockfall onto a glacier above which weathering had exploited pressure release joints in the parent outcrop prior to supraglacial transport. Without excavation it is difficult to test whether the rock rests on the limestone bedrock or on a bed of superficial sediment.

Figure 1. *Local footpath sign to the erratic.*

Its source rock is the Mont Blanc granite which lies 100 km due south from its current resting place. Early workers described the granite as 'protogine', a meta granite with a gneissic texture but this term is now obsolete. In the broader picture of the western Alps, the granite is one of a number of 'external crystalline massifs' which originated as late Variscan calc-alkaline potassic plutons (*c.* 300 Ma) intruded into gneissic basement of Late Proterozoic and Early Palaeozoic age. During the mid Tertiary Alpine orogeny, the granite

Figure 2. *The Pierre-à-Bot from the west side in winter (2005-12-22).*

Figure 3. *The Pierre-à-Bot in summer (2012-08-12).*

was heavily tectonised to form an elongate domal antiform. Exhumation and associated erosion in the Neogene and the Quaternary have created the modern landscape. Current glaciers around Mont Blanc are characterised by extensive covers of debris, particularly in the ablation zone. Much of this is sourced from the adjacent precipitous rock faces rising above the glaciers occupying the valley floors. Contemporary high rockfall activity rates are linked to both structural properties and permafrost degradation due to global warming (Fig. 4). Coutterand (2013) gives an excellent account of the current Mont Blanc glaciology and its Neoglacial changes in ice extent. Cosmogenic (10B) age determinations on surface samples taken at the top of the Pierre-à-Bot granite erratic have yielded age estimates of 21.4 ± 1.3 & 22.4 ± 1.2 ka BP confirming deposition at the Last Glacial Maximum (Graf et al 2015).

In the history of glacial geology, the Pierre-à-Bot is rightly renowned since it features prominently in the early to mid-nineteenth century debate surrounding the development of the 'Glacial Theory'. Recalling the eloquent words of the pioneer Scottish glaciologist James Forbes (1809–1868), this erratic is a 'stupendous monument of power'. He continued – 'It is impossible to look at it without emotion, after surveying the distance which separates it from its birthplace. No wonder that geologists have vied with one another in attempting to account for so extensive and surprising a phenomenon' (Forbes 1843). A memorial plaque affixed to the erratic is inscribed (in translation) 'To the memory of Louis Agassiz, Arnold Guyot, Edouard Desor, Leon Du Pasquier: pioneers of glaciology and Quaternary geology; this erratic block named toad stone was provenanced in the Mount Blanc massif

Figure 4. *Supraglacial debris in transit in the Mer de Glace ablation zone, as viewed from Montenvers. A large block approaching the size of the Pierre à Bot, close to the right-hand glacier margin, is circled in white (2014-09-12).*

and transported by the ancient Rhone Glacier' (see Fig. 5). A smaller plaque dating from 1993 marks the 100th anniversary of Amici Naturae, Société Suisse d'étudiants à Neuchâtel.

This paper seeks to trace the history of study of the erratic, its significance in the 'Glacial Theory' debate and its role in progressing the understanding of the processes of glacial sediment transport. For a detailed comprehensive global review of the development of glacial geology up to the late nineteenth century see Howarth (1893).

***Figure 5**. The main memorial plaque affixed (in 1966) to the Pierre-à-Bot erratic commemorating Louis Agassiz, Édouard Désor, Arnold Guyot and Léon Du Pasquier of Neuchâtel.*

The Jura

Neuchâtel (population 33,000) extends along the foot slopes of the Jura Mountains on the western shore of its eponymous lake. The lake lies at *c.* 430 m asl and the Pierre à Bot site at 708 m asl. Mont Tendre, the summit of the Swiss Jura attains 1679 m asl. The Jura, which give their name to the Jurassic System, consist of a series of concentric ridges to form an arc-like Alpine foreland extending for 360 km from the Rhine in the north to the Rhône in the south (Fig. 6). These ridges correspond to successive phases of folding and thrusting facilitated by an underlying Triassic evaporitic décollement horizon. Sedimentary rocks, dominated by limestones, form the bulk of the Jura and give rise to extensive areas of karst landscapes. To the east lies the Alpine foreland, a tract of Miocene molasse forming relatively low relief, bordered eastwards by the Alpine Bernese Oberland mountains.

The Last Glacial Maximum ice advance limit (LGM) of the Würm Alpine glaciation approximates to the watershed along the crest of the Jura although some of the higher areas sustained independent ice caps (Kelly et al 2004; Preusser et al 2011; Schlüchter et al 2021). The main ice stream which invaded the Jura initially flowed from south to north-trending valleys between

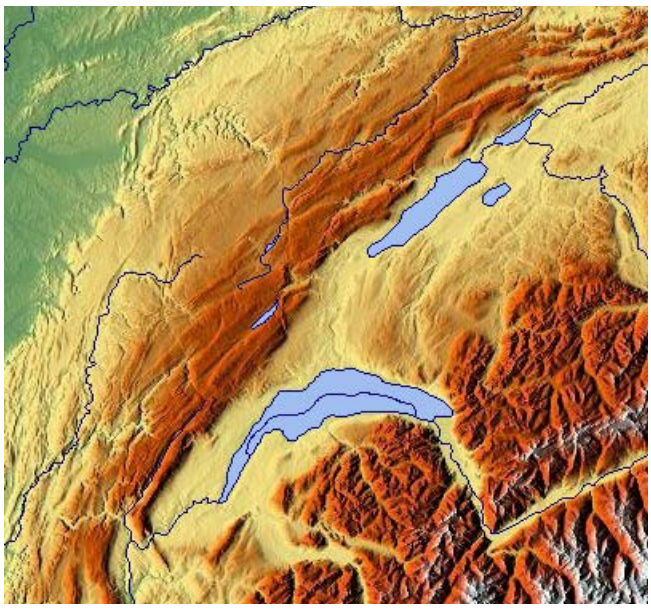

***Figure 6**. Relief map of the Juras and Western Alps with the intermediate Alpine foreland lowland.*

Martigny and Visp into what is now the middle Rhone valley and divided into two arms when it encountered the foothills. One piedmont lobe, the Valais Glacier, flowed north-east and terminated close to Solothurn, beyond Berne the Swiss capital, and the other (Rhône Glacier per se) flowed south-west past Geneva to terminate 20 km east of Lyon (Fig. 7). Arising from transfluence, the upper Rhone Glacier had become part of a complex transection system and was diverted south via the Simplon Pass.

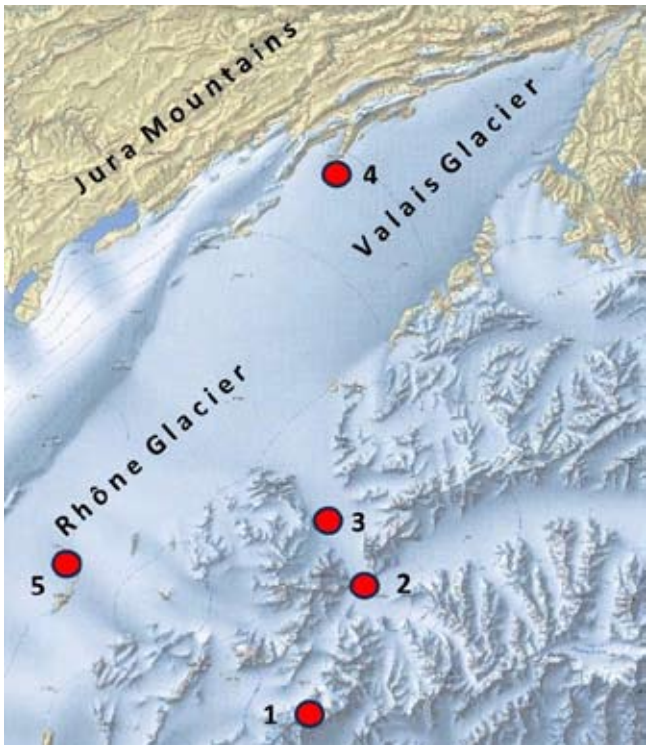

***Figure 7**. Glacier map at the Würm Glacial Maximum (LGM) for western Switzerland (C. Schlüchter, 2009). © Swiss Federal Office of Topography, swisstopo. 1. Mont Blanc; 2. Martigny; 3. Monthey; 4. Pierre à Bot/Neuchâtel; 5. Geneva.*

John Playfair and the Jura erratics

Along with the savants Sir James Hall (1761–1832) and Dr James Hutton (1726–1797), the academic mathematician/natural philosopher Professor John Playfair (1748–1819) of the University of Edinburgh, was a member of the eighteenth-century 'Scottish Enlightenment'. They were friends, and in 1788 they jointly discovered the dramatic unconformity at Siccar Point where the existence of 'deep time' was first recognised. Playfair famously wrote 'the mind seems to grow giddy by looking far back into the abyss of time'. In his 1795 classic *Theory of the Earth*, Hutton made some comments on former glaciation, aware that erratic blocks occur well beyond modern Alpine glaciers but there is no basis for the claim, contra Oldroyd (1996, 146), that he visited the Jura in the year before its publication.

Following Hutton's death in 1797, Playfair resolved to write his biography, but this was delayed (Playfair 1805), since by the turn of the century, Playfair's primary objective had changed. He decided to address the obscurities in Hutton's theory and present the plutonic and uniformitarian ideas in a more accessible form for the general public. The outcome was the publication of *Illustrations of the Huttonian Theory of the Earth* (Playfair 1802). Astonishingly, the mechanism for the emplacement of the Pierre à Bot and related blocks of Mont Blanc granite, which cropped out in-situ some 100 km to the south and were scattered across the eastern slopes of the Jura mountains (pages 385–394 on glaciers and torrents) was perceptively predicted by John Playfair. This was without the benefit at that time of having been to Switzerland or indeed any currently glaciated area (Note XV111 – Transportation of stones etc). He suggested that 'Ice would seem to afford a possible explanation of the transport of many masses [erratic blocks]; for the glaciers which descend the valleys of the northern regions are, like those of the Alps, charged with blocks which have fallen from the heights' (Playfair 1802, 173). Later he postulated that 'for the moving of large masses of rock, the most powerful engines without doubt which nature employs are the glaciers' (ibid, 388). Effectively, he laid the foundations of the 'Glacial Theory' two decades before its presentation by Louis Agassiz in 1837 (Seylaz 1962).

His associate Sir James Hall, returning from a cultural tour of Italy, visited some of the key localities relevant to the controversy surrounding the significance of the Jura erratic blocks. He wrote: 'on the face of the Jura, I rode through great assemblages of granitic blocks' (Hall 1815). Whether he visited the Pierre à Bot is unknown. At that time, Hall was particularly concerned to explain the streamlined bedrock morphology on Corstorphine Hill in western Edinburgh. In this he rejected the Hutton-Playfair glacial transport hypothesis and argued in favour of the erosive power of mud and boulders allied to a conjectural catastrophic mega-tsunami triggered by tectonic movements. Such ideas invoking debacles would be familiar to Playfair, since they were similar to the cataclysmic ideas promoted by the late eighteenth-century geologists such as the German savant Leopold von Buch, to account for Swiss erratic distribution.

John Playfair in 1816 made what appears to be the first documented field examination of the 'Pierre à Bot'. In the previous year, Playfair left Scotland for a seventeen-month excursion to France, Italy and Switzerland with the objective of familiarising himself with continental field geology which would help him write an updated second edition of his *Illustrations* supplemented by his own field observations. Alas, soon after his return, he died before he could complete the projected revision of his book. Fortunately, all was not lost since his nephew, James G. Playfair (1786–1857), was able to write a biographical account of his uncle's life including some details of his mainland European travels. This account confirms that Playfair senior had travelled from Paris to Neuchâtel and on entering the Jura he had encountered numerous 'loose blocks of granite, gneiss, and mica slate' littering a landscape underlain by limestone strata. 'The largest and most striking of them, the Pierre Abot [Pierre-à- Bot]... lies concealed in a wood upon the rapid slope of a hill, at an elevation of at least 700 feet [213 m] above that town, and measures 64 feet in length, 32 in breadth, and 16 in height. It contains, therefore, 32768 cubic feet, which (allowing 13 cubic feet of granite to a ton) gives a weight of 2520 tons'. Importantly, he found no evidence which would falsify his glacial transport hypothesis for the emplacement of the granite erratic blocks. 'A glacier... [which] conveys the rocks on its surface free from attrition, is the only agent we now see capable of transporting them such a distance, without destroying that sharpness of the angles so distinctive of these masses' (Playfair 1822, xxviii-xxx).

Interestingly, Playfair's successor at Edinburgh as professor of mathematics was John Leslie (1766–1832). He also had an interest in glaciation and had visited the Swiss Alps in 1796 specifically to seek evidence of climatic change. This he identified in the sequences of end moraines that had been created by numerous Neoglacial valley glacier fluctuations and in the clear evidence of progressive colonisation by vegetation of these as the glaciers retreated (Leslie 1804; Hoffman 2018).

Observations of Henry De la Beche

Following his marriage in 1818, in the following summer, Henry Thomas De la Beche (1796–1855) took his new wife and mother-in-law on a year-long continental tour which was described by McCartney (1977, 12) as a 'kaleidoscope of various scientific activities, important family events, and new cultural experiences'. It should be recalled that De la Beche became the de facto Director of the government-funded British Geological Survey when it was founded in 1835. He kept a series of pocket journals, and the one covering

the period 31st January–15th March 1820 records his travel to Neuchâtel, Geneva, Chaumont in Switzerland, and Turin, Genoa, Marengo, Pisa and Florence in Italy. (National Museum of Wales, NMW 84.20G.D347.) On the 6 February 1820, De la Beche wrote 'At about 800 feet [244 m] above the lake of Neuchatel Mr. de Montillon took me into part of the Forest where among several large blocks of granite which rest on calcareous beds of the Jura there was one in particular remarkable for its enormous size. It is about 40 feet [12 m] high etc. Its component parts are Quartz, Feldspar, a little black mica with chlorite' (Sharpe and McCartney 1998) (Fig. 8). He made two sketches of the enormous block (see A and B, Figs. 9 & 10), and although he didn't record its name as the Pierre-à-Bot, there is no doubt about its identity. Each sketch was drawn full page sideways across horizontally lined pages. Apart from these, only a few scrappy sketches were included in this particular pocket book. Sketch A has been published previously by North (1943, 6; Chorley et al 1964, 195), who omitted to identify the block as the Pierre-à-Bot and incorrectly dated the sketch as 1819, and Rudwick (2008, 81; 2014, 117). Sketch B, as far as is known, has not been published previously.

***Figure 8**. Close-up of the Mont Blanc granite forming the Pierre à Bot erratic. Scale is a UK £1 coin.*

Subsequently, De la Beche gave no opinion in print on the genesis of the Pierre-à-Bot nor included his two sketches of it in any of his own publications. He appears to have preferred to 'sit on the fence' although some clues to his thinking can be gleaned from his educationally oriented book *A Geological Manual* (De la Beche 1832). Perhaps wisely he stated, 'Solutions of the problem of erratic blocks seem not very practical at present, and our attempts at general explanations can be considered little else than conjectures that may appear more or less probable. The student, therefore, should be careful not to consider such explanations as well ascertained truths, but more as hypotheses, which future and extensive observations may, or may not, prove correct' (ibid, 168). He continued: 'From my own

***Figure 9**. Sketch A of the Pierre-à-Bot, drawn by Henry De la Beche in 1819 (©National Museum of Wales De la Beche archive).*

***Figure 10**. Sketch B of the Pierre à Bot, drawn by Henry De la Beche (©National Museum of Wales De la Beche archive).*

observations, I can fully confirm the remarks of various authors respecting the situation of Alpine blocks, and their probable derivation from the respective valley, which they, as it were, appear to face... The levels which the [erratic] blocks keep on the Jura... has been often observed by other authors. Such a common mode of occurrence must, we should suppose, have some common cause, and can scarcely be accidental'.

Having made a detailed assessment of all the diary entries arising from De la Beche's tour, McCartney (1977, 15), felt that 'If any aspect of Alpine geology was especially noted by De la Beche, it was the force of debacles... Avalanches, torrents and glaciers impressed him by their ability to move vast quantities of heavy material to locations a great distance from their original sites'. Current Alpine earth surface process dynamics clearly impressed him. Many of the sketches he made on the tour were later published as annotated sections and views to illustrate a wide range of geological phenomena (De la Beche 1830).

Louis Agassiz, William Buckland and 'The Glacial Theory'

This theory did not emerge overnight. Rather, it was the culmination of several decades of field observation and debate by a number of workers. Davies (1967) provides an excellent overview in his chapter eight

'The Glacial Key' and although he does not name the Pierre-à-Bot per se he does mention a 'monster block of granite weighing 2520 tons'. In the present context only those publications pertinent to the Jura erratic block problem will be considered. Inevitably, Louis Agassiz (1807–1873) steals the limelight since his key contributions both oral and written were undertaken whilst employed in Neuchâtel during the period 1837–1840 (Agassiz 1837; 1840).

Robert Jameson (1774–1854) held the chair of Natural History in the University of Edinburgh for 50 years and for some 30 years he was the editor (he called himself the conductor) of the Edinburgh (New) Philosophical Journal. Having studied at the renowned Bergakademie under Werner in Freiberg, in the then Kingdom of Prussia, he had a very European outlook and encouraged the publication of papers in his journal by continental workers, often organising the translation of them into English. Over the period 1836–1839 translations of five glacially related papers were published by him in his journal. The first two papers were authored by Jean de Charpentier (1835; 1841) and argued both for a former extensive glaciation of Switzerland, and that Alpine glaciers had extended to the Jura foothills as a result of the Alps having been uplifted well beyond their current elevation. He identified a huge granite erratic on the western slope of the Rhône valley at Monthey, La Pierre des Marmettes (Figs. 11 & 12). Another paper was by Agassiz (1838) 'On the erratic blocks of the Jura' in which he recorded that the angular blocks were separated from the polished/striated bedrock surface by a sedimentary layer up to several metres in thickness. Significantly, this was published within a year of Agassiz's renowned *Discourse de Neuchâtel*' in 1837. In journalistic terms it was a scoop! Agassiz's principal conclusion was that the erratic blocks and eroded bedrock had resulted from glacial processes rather than catastrophic diluvial currents. He also acknowledged that his ideas were inspired by the earlier work of the Swiss engineer Ignace Venetz and geologist Jean de Charpentier by dedicating his new masterpiece *Études sur les glaciers de la Suisse* jointly to them, Agassiz (1840). He described the shape of the Jura erratic boulders as 'generally angular and devoid of traces of abrasion or friction, and they recall perfectly the great blocks of granite which break loose in the Alps along their large-scale system of joints'. He stated that 'the famous Pierre-à-bot boulder, which has a volume of about 352 m³ occurs on that horizon at an elevation of 708 m' asl.

His first visit to Britain was in 1834 as a guest of William Buckland (1784–1856), Reader in Geology at Oxford University, and this started a life-long friendship through their shared interest in fossil fishes. As the pendulum supporting the hypothesis of former widespread glaciation swung in its favour, the diluvialist Buckland's curiosity increased. In October 1838 he was an invitee of Agassiz in Neuchâtel and predictably he was shown the nearby south-eastern slope of the

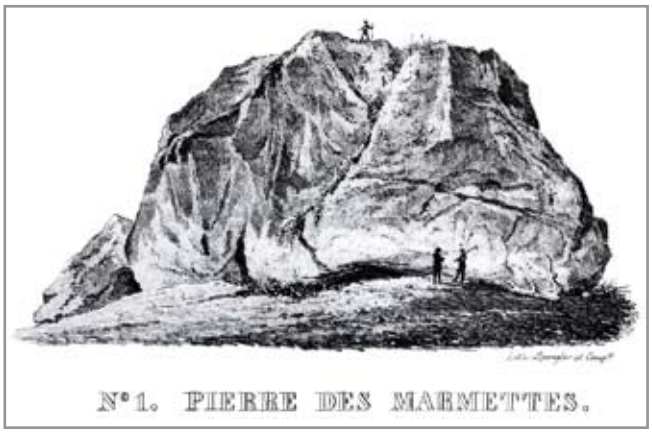

Figure 11. *La Pierre de Marmettes formed of a block of Mont Blanc granite, possibly the largest glacial erratic in Switzerland at c. 3000 tons (Plate 1 of Charpentier's seminal book of 1841).*

Figure 12. *La Pierre de Marmettes as seen in 2012, with a stairway leading to a pavilion constructed on the top bordering the car park of Monthey hospital c. 5 km south-west across the Rhone Valley from the Bex salt mines where de Charpentier was the manager.*

Jura to examine the erratics, polished, furrowed and striated bedrock, the tell-tale field evidence of former glaciation. It is hard to imagine that he didn't see the local celebrity mega erratic, the Pierre-à-Bot. Certainly, contra to the claim by his biographer Chapman (2020, 141), he was unable to 'inspect glaciers in the Jura', simply because they had all melted before 10 ka BP! Nevertheless, at that stage Buckland still remained sceptical of the glacial transport mechanism but after he had been taken into the Bernese Oberland, where the critical evidence occurred in close proximity to present day glaciers, Buckland became convinced that Agassiz was correct in his interpretation. This 'conversion' gave rise to Agassiz's reciprocal visit to Britain in 1840 since they had resolved to jointly seek comparable evidence in Britain. By chance, the annual meeting of the British Association for the Advancement of Science was taking place in Glasgow. As part of the proceedings of Section C, Agassiz read his paper (in French) 'On glaciers and boulders in Switzerland' (Agassiz 1841), drawing upon his just-published book. He described how the side of the

Jura facing the Alps was both polished and had a scatter of angular erratic blocks at different levels. Section C was then called Geology and Physical Geography, with two presidents, respectively Charles Lyell and George Bellas Greenough. The section's three vice presidents were Buckland, De la Beche and James Smith (of Jordanhill). Smith was chair of the session at which Agassiz gave his paper. Indeed, virtually all the leading British geologists were in attendance. Coincidentally, Smith had also given a paper to the section repeating his earlier published findings of an arctic molluscan fauna in the raised estuarine sediments of the Clyde estuary (Hoffman 2015).

Subsequently, in Agassiz (1842, 228), he revealed that he had indulged in some urban geological fieldwork in Glasgow before giving his paper, by examining a number of temporary sections at active construction sites. These exposed glacial till characterised as '… rounded, polished and scratched blocks of very various dimensions... every where indiscriminately mixed together in a marly or clayey paste'. This finding supported his epic declaration that within the Glasgow urban area there was clear evidence of past glaciation similar to that in Switzerland and he also confidently anticipated that in the Scottish Highlands, particularly in the Ben Nevis area, evidence of glaciation would be identified. This prediction was heavily criticised by Roderick Murchison and others at an 1841 meeting of the Geological Society of London, a scepticism which was to persist for two decades.

Another anglophone who was present at the Glasgow meeting was James Forbes (1809–1868), the Professor of Natural Philosophy (physics) in the University of Edinburgh. He undoubtedly examined the Pierre-à-Bot on 18th September 1841 in the company of Louis Agassiz and Édouard Desor and again nine months later on 13th June 1842. On both occasions he sketched the erratic. One of these sketches was published in his now classic account of his travels through the Alps (Forbes 1843; and Fig. 13). This woodcut formed the header page illustration to his Chapter 3 'On the geological agency of glaciers'. Paradoxically, during 1841–42 Forbes was sceptical about some aspects of the glaciological implications of the 'Glacial Theory' and had misgivings with some of Agassiz's explanations, particularly with the implied degree of cooling required to enable glaciers to extend so far from their Alpine sources. At that time, he doubted the ability of a glacier to extend from the Mont Blanc Alps to the Jura with such a low surface gradient. Cunningham (1990) provides a valuable detailed biography of Forbes which emphasises his major contributions to glaciology but, sadly, is marred by numerous typographical errors.

Final acceptance of the 'Glacial Theory'

Andrew. C. Ramsay (1814–1891), who ultimately succeeded Murchison as Director of the British Geological Survey in 1871, had a particular interest in glacial geology and in the preface to his book *Old Glaciers* succinctly summarised the sorry state of affairs two decades after the formulation of the Agassiz-Buckland glaciation of Britain hypothesis in saying 'With rare exceptions those who cared at all about it, met the glacial theory of the drift in general, and that of extinct glaciers in particular, with incredulity, and sometimes with derision' (Ramsay 1860), although the select group of believers included William Buckland, Robert Chambers, Charles Darwin, James Forbes, and Charles Maclaren. Originally the text of Ramsay's book had been published in *Peaks, Passes and Glaciers* (Ball 1859).

In his younger days Ramsay was an Alpinist making visits to the Swiss Alps in 1852, 1858, 1860 and 1862 (Geikie 1895). In particular he was familiar with the Aar Glacier that Agassiz earlier had studied closely. Yet despite this experience he had an alternative explanation for 'those celebrated blocks of which Pierre-à-Bot is the most conspicuous'. After citing Playfair, Venetz, Charpentier and Forbes, he disagreed with their contention that the Rhone palaeoglacier

***Figure 13**. Sketch of the Pierre-à-Bot drawn by James Forbes in either 1842 or 1843.*

had spread ground moraine and the associated granite blocks over the lower ground between the Oberland and the Jura. He interpreted exposures he had examined in this area as stratified marine boulder beds indicative of aqueous deposition where glaciers had entered the sea and posited that an ice-marginal glaciomarine submergence of Switzerland at least 2000 feet [609 m] deep had been coeval with the glaciation (Figs. 14 & 15). He wrote of how 'the stranded bergs deposited their freights, sometimes including those gigantic blocks that now astonish the traveller' (Ramsay 1860, 33). This interpretation was undoubtedly influenced by his mapping experiences in Britain for the Geological Survey and in particular interbedded fluvial–till sequences which he viewed as the sedimentary signatures of sub-aquatic environments. This thinking appears to have been a hangover from pre-Glacial Theory (1840) diluvial ideas. Astonishingly, even over two decades later Ramsey still believed in a major glacial submergence event up to 2000 feet [609 m] in North Wales during the Last Ice Age (Ramsay 1878, 411–431; Ramsey et al 1881, 278). Michael Roberts (pers. comm.) has found an erratic at 2500 feet [762 m] in the Berwyns, south of Snowdonia.

Figure 14. *Ice-bergs in Paradise Bay, Gerlach Strait, western Antarctic Peninsula. 64°49'26"S 62°49'26"W. (2009-02-07).*

Figure 15. *Close-up view of a boulder and other smaller clasts on an ice raft in Paradice Bay. With further melting, these rocks will be released sinking to the sea bed as drop-stones. Note the dip of the stratification in the ice, enhanced by the multiple beds of fine sediment.*

A seemingly overlooked footnote (pp 33–34) in Ramsay's 1860 book is of noteworthy interest. In a letter from Charles Darwin to Ramsay (*c.* 1859/60), Darwin astutely pointed out that according to Agassiz the Jura erratic blocks lie *on and in* stratified sands and gravel 'yet he explains all the phenomena by *glacial* action alone'. Speculatively Darwin suggested 'that the country was partially submerged, and icebergs derived from Alpine glaciers floated the blocks to the Jura'. Ramsey refers to this mechanism citing the very first edition of Darwin's classic 'Journal and Remarks' which much later became known as *The Voyage of the Beagle* (Darwin 1839). That Darwin intervened should be no surprise since they regularly corresponded and socialised with Ramsey acting as his geological sounding board.

After returning from his Beagle voyage Darwin gave priority to writing-up his journal for publication in the official report series (Darwin 1839). A delay due to Captain Fitz-Roy's tardy completion of his allied report enabled Darwin to add an extensive addendum to his text (pp 609–629). Clearly, he had used the additional time to read widely and had mastered the then current literature on the 'Glacial Theory' and Agassiz's proposed land-ice glaciation. However, he felt that he could not accept Agassiz's rejection of floating ice as a viable widespread mechanism for erratic transport that had been promoted by Lyell. In the context of the Jura, Darwin drew on his Tierra del Fuego observations of glaciers calving into the sea and the drifting of icebergs carrying debris. In his argument, he made two assumption: (a) an arm of the sea had occupied the lowlands between the Jura and the Alps, followed by (b) a slow tectonic elevation of Switzerland causing a regressive sea level. Glaciers flowing into the sea had generated ice-rafted erratics and within the zone defined by the lower and upper tidal limits, grounding of icebergs laden with rock clasts had striated the exposed bedrock. Over time, progressive land uplift would have resulted in this process extending downwards over the Jura bedrock slopes. In addition, littoral sedimentation would have buried the ice-eroded bedrock. In 1841, Darwin sent Agassiz a copy of his journal and admitted regret for his criticism of Agassiz's terrestrial glaciation concept. However, he maintained a belief that submergence and associated icebergs was an element in the deglaciation process.

A late convert to the land-ice hypothesis was Charles Lyell (1795–1875). Fortunately, his sister-in-law, Katherine Lyell (1817–1915) was able to arrange the posthumous publication of his letters etc (Lyell, K.M. 1881). During August–September 1857 he was on a geological tour in Switzerland and regularly wrote to his father-in-law geologist Leonard Horner who served as President of the Geological Society on two occasions. In the context of the 'Glacial Theory', the key letter to Horner was dated August 14. We learn from this that Lyell had just been in the Neuchâtel area and that he had *revisited* the Pierre-à-Bot and seen the zone

***Figure 16**. Mont Blanc (4810 m) 70 km distant, seen from Lac Leman (Lake Geneva). It was the conceptual difficulty of imagining glaciers extending from their source around Mont Blanc to over 100 km which delayed the acceptance of the land transport hypothesis in the Alps-Jura foreland area. (2023-12-25).*

of blocks of Monte Rosa talcose granites and gneiss on one level of the Jura. It is likely that his first encounter with the Pierre-à-Bot was in July–August 1818 whilst he was still a second-year undergraduate, travelling with his family from Lausanne to Basel (Wilson 1972). After his second visit he expressed sentiments which mirror those of Forbes (1843) cited above, 'that Pierre-à-Bot is really more wonderful when seen again, than when I first beheld it, so vast and angular, so clearly resting on a limestone chain'. He mused that 'we have also in Angus [Scotland] our Pierre-à-Bot… a black mica schist block… on the hill of Turin (NGR NO 515 535, 6 km north-east of Forfar) resting on Old Red Sandstone… and must have come from the Grampians, probably very far from north west'. John Gordon (pers. comm.) has suggested that Lyell was mistaken and that he was referring to Pitscandy Hill, spot height 211 m, which lies *c*. 2 km south-west of Turin Hill (NGR NO 501 532).

Lyell also explicitly mentions several factors which clearly had influenced his change of mind — (a) lack of marine fossils in the gravel, mud and moraine, (b) the even spread of travelled erratic blocks, (c) the distinctive morphology of many valleys, and above all (d) the sight of Alpine snow at Berne and elsewhere (Fig. 16). These in combination 'made me strongly incline, with Charpentier, Agassiz, and others, to embrace (as James Forbes did), the theory of a terrestrial glacier'. This was his first declaration that he was now abandoning his previously favoured marine ice-berg mechanism for all erratic block transport. A fuller exposition was included in Lyell (1863; and Fig. 17).

As recorded by Archibald Geikie (1835–1924), a major paradigm shift in 1862 led to both he and Ramsey into changing their views to an acceptance of land ice as being responsible for the deposition of the bulk of terrestrial glacigenic (drift) sediments (Worsley 2008; 2019; Rose 2021) from one of glaciomarine ice linked to a hypothetical submergence. Later, in his *Textbook of Geology*, Geikie (1885), includes Forbes's (1843) drawing of the Pierre-à-Bot along with its dimensions. In addition, Geikie constructed his own north–south cross-section from the Alps to the Jura across what he termed the plain of Switzerland (fig. 145, 396), depicting the postulated supraglacial granite erratic transport path (Fig. 18). In a thorough review of the Swiss erratic block topic, Lubbock (1896, 113) suggested that the time taken for the movement of the erratic 100 km from Mont Blanc to Neuchâtel was *c*.1 ka. This value was derived by assuming an average annual flow rate of modern Alpine glaciers of *c*.100 m a^{-1}.

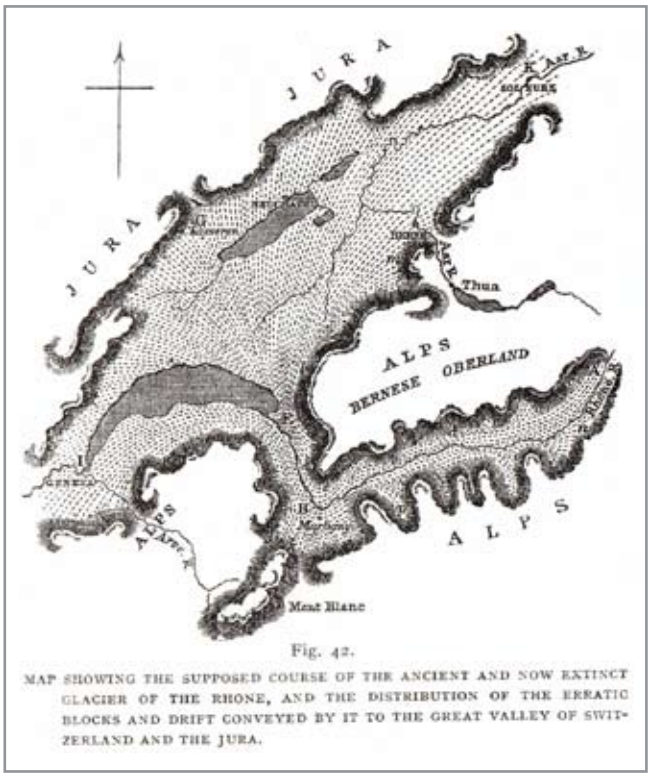

Fig. 42.

MAP SHOWING THE SUPPOSED COURSE OF THE ANCIENT AND NOW EXTINCT GLACIER OF THE RHONE, AND THE DISTRIBUTION OF THE ERRATIC BLOCKS AND DRIFT CONVEYED BY IT TO THE GREAT VALLEY OF SWITZERLAND AND THE JURA.

***Figure 17**. After his 'conversion', Lyell fully embraced the work of Guyot and others, in the land ice hypothesis for the conveyance of Mont Blanc erratics to the Jura. This figure is reproduced from Lyell (1863) figure 42.*

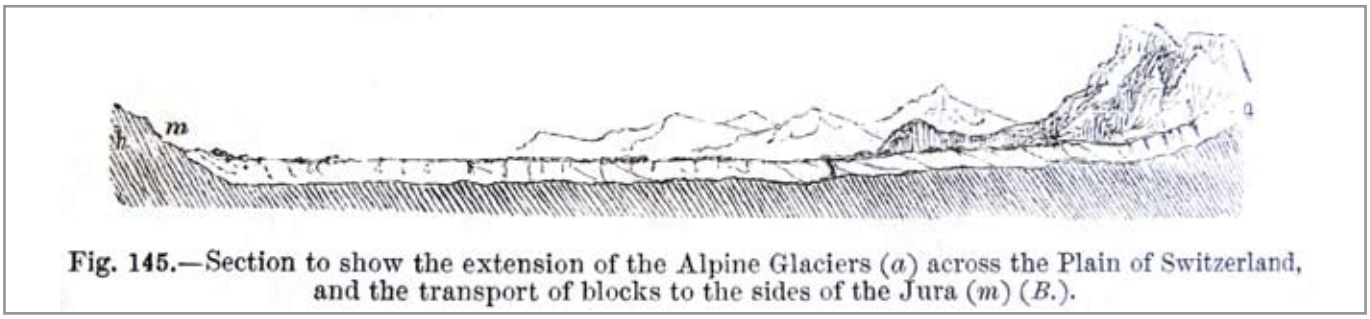

Fig. 145.—Section to show the extension of the Alpine Glaciers (*a*) across the Plain of Switzerland, and the transport of blocks to the sides of the Jura (*m*) (*B.*).

***Figure 18**. Long-section of a hypothetical glacier extending from Mont Blanc to the Juras created by Arch. Geikie and included in his Textbook of Geology (fig. 145, 396): 'Section to show the extension of the Alpine Glaciers (a) across the Plain of Switzerland and the transport of blocks to the sides of the Jura'.*

Concluding comment

With the editor's connivance, an unconventional ending to this paper might be in the form of a two-part 'pub quiz' type of question. First, 'what links the British geologists John Playfair, Henry De la Beche, William Buckland, James Forbes, Charles Lyell and Andrew Ramsay?' — answer — *they all independently examined the same granite erratic block in the Jura foothills*. Second, 'what links the Swiss glacial workers Louis Agassiz, Arnold Guyot, Édouard Desor and Léon Du Pasquier?' — answer — *the Neuchâtel Academy and the Pierre-à-Bot erratic*.

This paper is dedicated to Tony Waltham lead Editor of the Mercian Geologist 2000–2019 and President of the East Midlands Geological Society 2021–2024.

Synopses of the four glacial geologists named on the Pierre à Bot memorial plaque.

[**Jean**] **Louis** [**Rodolphe**] **Agassiz** (1807–1873). Born in Môtier, a village 15 km SE of Neuchâtel. Studied medicine at Zurich, Heidelberg & Munich. Primarily a zoologist (modern and fossil fish) but for the decade from 1835 was based largely in Neuchâtel and focused on glaciology and glacial geology. Emigrated to the USA in 1846 and was soon appointed Professor of Zoology and Geology at Harvard University. He remained in the USA and his impact was such that Irmscher (2013) named him as the 'creator of American science', but alas, ultimately fell into professional ignominy.

Arnold [**Henri**] **Guyot** (1807–1884). Born in Boudevilliers, 5 km north of Neuchâtel. Followed graduate studies in Germany and later became a member of the Neuchâtel Academy and also a colleague of Agassiz. Mapped the distribution of glacial erratics in Switzerland (Wannier 2023). In 1848 he followed Agassiz and emigrated to USA and became the first professor of geology at what was to become Princeton University in 1854. Guyot (seamount) named by H. H. Hess after him. An erratic boulder of conglomerate from the Neuchâtel vicinity forms a memorial to Guyot on the Princeton campus (Bernoulli & Capuzzo 2021).

[**Pierre Jean**] **Édouard Désor** (1811–1882). Born Freidrichsdorf, near Frankfurt-on-Main, Germany. Desor had a geological and legal training and had worked on Jura echinoderms and its rock structure. In 1837 he became amanuensis (secretary) to Agassiz. Spent eight summers at the 'Hotel des Neuchâtelois', a refuge on the Aar Glacier. He was the first to identify fossiliferous interglacial deposits of Switzerland. In 1848 he also emigrated to the USA but fell out with Agassiz and in 1852 returned to Neuchâtel as professor of geology. Following an inheritance in 1858, which gave financial independence, he also turned to politics and became president of the Swiss Federal Assembly in 1874.

A plan by Agassiz, Guyot and Désor to write a three-volume work '*Système Glaciaire*' respectively covering glaciers, erratics and glaciation outside Switzerland never progressed beyond volume one which was the work of Agassiz (1847). This was partly due to the 1848 anti-aristocratic revolution which saw the Canton of Neuchâtel joining the Swiss Federal state. The former Prussian controlled principality of Neuchâtel was abolished in 1857 leading to the closure of the original Neuchâtel Academy. It was re-established in 1866.

Léon Du Pasquier (1864–1897) Born in Neuchâtel. Geological studies in Berlin and Zurich. From 1895 teacher at the Neuchâtel Academy. Studied the glacial geology of northern Switzerland particularly morainic landforms and allied river terraces. Identified two and probably three glacial stages and intervening interglacials. Subsequently worked on the palaeo-Rhone (Valais) glacier sediments in the Jura.

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References

Agassiz, L. 1837. *Discourse of Neuchâtel* + Agassiz, L. 1840. *Études sur les glaciers de la Suisse*. Neuchâtel: Jent et Gassmann, 213 pp + atlas de 32 planches. These were translated and edited by A. V. Carozzi of the University of Illinois, 1967, New York, Hafner Publishing Company.

Agassiz, L. 1838. On the erratic blocks of the Jura. *Edinburgh New Philosophical Journal*, **24**, 176-179.

Agassiz, L. 1841. On glaciers and boulders in Switzerland. *Report of the British Association for the Advancement of Science* (Glasgow, Aug 1840), trans of sections, 113-114.

Agassiz, L. 1842. The Glacial Theory and its recent progress. *Edinburgh New Philosophical Journal*, **33**, 217-283.

Agassiz, L. 1847. *Système glacière, ou recherches sur les glaciers. Première partir. Nouvelles études et expériences sur les glaciers actuels, leur structure, leur progression, et leur action physique sur le sol*. Paris: Victor Masson, 1, xxxi+598 pp.

Ball, J. 1859 (ed.) *Peaks, passes and glaciers: a series of excursions by members of the Alpine Club*. London: Longman, Green, Longman and Roberts, 520 pp.

Bernoulli, D. & Capuzzo, N. 2021. The voyage of the 'Guyot Stone' from the Swiss Alps to Neuchâtel and Princeton. *International Journal of Earth Sciences*, **110**, 3015-3022.

Chapman, A. 2020. *Caves, coprolites, and catastrophes: the story of pioneering geologist and fossil hunter William Buckland*. London: Society for Promoting Christian Knowledge, 256 pp.

Charpentier, J. de 1835. Notice sur la cause probable de transport des blocs erratiques de la Suisse. *Annales des Mines*, ser 3, **8**, 219-236.

Charpentier, J. de 1841. *Essai sur les glaciers et sur le terrain erratique du basin du Rhône et sur le terrain erratique du Basin du Rhone*. Lausanne: Marc Ducloux, x+363 pp.

Chorley, R. J., Dunn, A. J. & Beckinsale, R. P. 1964. *The history of the study of landforms. Volume one: geomorphology before Davis*. London, Methuen & Co Ltd, 678 pp.

Coutterand, S. 2013. *Les glaciers du Mont-Blanc*. Chamonix: Editions Atelier Escope, 160 pp.

Cunningham, F. F. 1990. *James David Forbes: pioneer Scottish glaciologist*. Edinburgh: Scottish Academic Press, 329 pp.

Darwin, C.[R]. 1839. *Journal and remarks 1832–1836* [Voyage of the Beagle]. London: Henry Colburn, 615 pp.

Davies, G. L. 1967. *The earth in decay: a history of British geomorphology 1578 to 1878*. London: Macdonald Technical and Scientific, 390 pp.

De la Beche, H. T. 1830. *Sections and views illustrative of geological phenomena*. London: Truettel & Wurtz, 71 pp.

De la Beche, H. T. 1832. *A geological manual*. 2nd ed. London: Truettel & Wurtz, viii+535 pp.

Forbes, J. D. 1843. *Travels through the Alps of Savoy and other parts of the Pennine chain with observations on the phenomena of glaciers*. Edinburgh: Adam and Charles Black, 424 pp.

Geikie, A. 1885. *Textbook of Geology*. 2nd ed. London: Macmillan, 992 pp.

Geikie, A. 1895. *Memoir of Sir Andrew Crombie Ramsay*. London: Macmillan, 397 pp.

Graf, A., Akçar, N., Ivy-Ochs, S., Strasky, S., Kublik, P. W., Christi, M., Burkhard, M., Wieler, R. & Schlüchter, C. 2015. Multiple advances of Alpine glaciers into the Jura Mountains in northwestern Switzerland. *Swiss Journal of Geoscience*, **108**, 225-238.

Hall, J. 1815. On the revolutions of the earth's surface. Parts 1 & 2. *Transactions of the Royal Society of Edinburgh*, **7**, 139-211, 4 plates.

Harmer, F. W. 1928. The distribution of erratics and drift. *Proceedings of the Yorkshire Geological Society*, **21**, 83-150.

Hoffman, P. F. 2015. The tooth of time: James Smith of Jordanhill. *Geoscience Canada*, **42**, 7-25.

Hoffman, P. F. 2019. True glacial warming inferred from Alpine moraines by Scottish physicist John Leslie in 1796. *Earth Science History*, **38**, 204-214.

Howarth, H. 1893. *The glacial nightmare and the flood, a second appeal to common-sense from the extravagance of some recent geology*. London: Sampson, Low, Marston & Co. 2 vols, xxiii, xii, 920 pp.

Irmscher, C. 2013. *Louis Agassiz: creator of American science*. Boston: Houghton Mifflin Harcourt, 434 pp.

Kelly, M. A., Buoncristiani, J-F. & Schlüchter, C. 2004. A reconstruction of the last glacial maximum (LGM) ice-surface geometry in the western Swiss Alps and contiguous Alpine regions in Italy and France. *Eclogae Geologicae Helvetiae*, **97**, 57-75.

Leslie, J. 1804. *An experimental inquiry into the nature and propagation of heat*. London: J. Mawman, vii, 562 pp.

Lubbock, J. 1896. *The scenery of Switzerland and the causes to which it is due.* London: Macmillan, xxxv, 480 pp.

Lyell, C. 1863. *The geological evidences for the antiquity of man: with remarks on theories of the origin of species by variation*. 1st Ed. London: John Murray, xii, 520 pp.

Lyell, K. M. 1881. (ed.) *The life, letters and journals of Sir Charles Lyell, Bart*. Vol 2. London: John Murray, 520 pp.

McCartney, P. J. 1977. *Henry De La Beche: observations on an observer*. Cardiff: Friends of National Museum of Wales, 77 pp.

North, F. J. 1943. Centenary of the Glacial Theory (notes on manuscripts and publications relating to its origin, development and its introduction into Britain). *Proceedings of the Geologists' Association*, **54**, 1-28.

Oldroyd, D. R. 1996. *Thinking about the earth: a history of ideas in geology*. Cambridge, Mass: Harvard University Press, 410 pp.

Playfair, J. 1802. *Illustrations of the Huttonian Theory of the earth*. Edinburgh: William Creech, xx, 528 pp.

Playfair, J. 1805. Biographical account of the Late Dr. James Hutton F.R.S. Edin. *Transactions of the Royal Society of Edinburgh*, **5** (3), 39-99.

Playfair, J. G. (ed.) 1822. Biographical account of the late Professor Playfair. In: *The works of John Playfair*, **1**, Edinburgh: A. Constable & Co., xi-Ixxvi + 514 pp.

Preusser, F., Graf, H. R., Keller, O., Krayss, E, & Schlüchter, C. 2011. Quaternary glaciation history of northern Switzerland. *E&G Quaternary Science Journal*, **60**, 282-305.

Ramsay, A. C. 1860. *The old glaciers of Switzerland and North Wales*. London, Longman, Green, Longman and Roberts, 116 pp.

Ramsay, A. C. 1878. *The physical geology and geography of Great Britain*. 5th ed. London: Edward Stanford, 639 pp.

Ramsay, A. C., Salter, J. W. & Etheridge, R. 1881. The geology of North Wales. 2nd ed. *Memoirs of the Geological Survey of Great Britain and of the Museum of Practical Geology*, **3**, 607 pp.

Rose, J. 2021. Lyell, the Geikies and Croll's observations on terrestrial glacial sediments and landforms. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, 112 (3/4), 261-274.

Rudwick, M. J. S. 2005. *Bursting the limits of time*. Chicago: University of Chicago Press, 708 pp.

Rudwick, M. J. S. 2008. *Worlds before Adam*. Chicago: University of Chicago Press, 614 pp.

Rudwick, M. J. S. 2014. *Earth's deep history: how it was discovered and why it matters*. Chicago: Chicago University Press, 360 pp.

Sharpe, T. & McCartney, P. J. 1998. *The papers of H. T. De la Beche (1796–1855) in the National Museum of Wales*. Cardiff: National Museum & Galleries of Wales, 257 pp.

Schlüchter, C. (compiler) 2009. *Switzerland during the last glacial maximum (LGM)*, 1:500,000 Geomaps500. Bern: Swiss Federal Topographic Mapping Office.

Schlüchter, C., Akçar, N. & Ivy-Ochs, S. 2021. The Quaternary Period in Switzerland. In: *Landscapes and landforms of Switzerland* /edited by E. Reynard. Springer Nature Switzerland AG, pp 47-69.

Seylaz, L. 1962. A forgotten pioneer of the Glacial Theory: John Playfair (1748-1819). *Journal of Glaciology*, **4**, 124-126.

Waltham, T. 2007. *The Yorkshire Dales: landscape and geology*. Ramsbury: Crowood Press, 224 pp.

Wannier, M. M. A. 2023. No publication, no fame: reassessing Arnold Guy's (1807–1884) pioneering contributions to the glacial theory. *Earth Science History*, **42**, 123-159.

Wilson, L. G. 1972. *Charles Lyell: The years to 1841: The revolution in geology*. New Haven: Yale University Press, 553 pp.

Worsley, P. 2008. Esmark's end moraine and the glacial theory from a British perspective. *Earth Science History,* **27**, 12-30.

Worsley, P. 2019. Archibald Geikie as a glacial geologist. In: Betterton, J., Craig, J., Mendum, J.R., Neller, R. & Tanner, J. (eds). Aspects of the life and works of Archibald Geikie. *Special Publication Geological Society*, **480**, 191-212.

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