REVIEW

"The Earth Calculus": Babbage, tables, and the calculating machine in the study of geology

Carla Petrocelli[1]

Abstract

Charles Babbage is best known as a pioneer of computer science, but his contributions to the study of the Earth are not as well known. A curious and tireless traveler, on one of his trips to Italy, he dwelt on the remains of the Temple of Serapis, located about one-hundred feet from the coast of the small bay near Pozzuoli, south-west of Naples. On his return to England, also using his Difference Engine, he developed a theory to explain the phenomena related to the area of Serapeo, accompanied by illustrations and mathematical calculations, aimed at explaining the geological phenomena that had helped to make the site so interesting. With the same precision used for his calculation engine, Babbage proposed innovative techniques for the printing of diagrams and tables to be used in earth sciences. Just as his calculation engine had to be reliable by helping to eliminate human error, so the innovative techniques proposed had to allow a representation of geology as a reliable scientific experience.

1 Introduction

A forward-thinking mind, mathematician, philosopher of science, physicist, social engineer, scientific reformer, statistician, economist, geologist, Charles Babbage (1791–1871) was also interested in astronomy, cryptology, railway safety, constants in nature, lighthouses, the postal systems and the relationship between science and religion. Today he is mainly known as the pioneer of modern computing, but his contributions related to the study of the Earth are certainly not as well known.

Born on December 26, 1791 in London, and not in 1792 in Devonshire, as erroneously reported by many scholars misled by the date reported in his obituary in *Nature*[1] in 1871, in his life Babbage suffered the fascination of everything mechanical enough to become a keen observer of technological changes based on the introduction of machines in nineteenth-century England (Romano 1982:386–388). Immediately after finishing his studies at Trinity College in Cambridge, where he had arrived in the spring of 1810, he had been concentrating on constructing a machine, the

Difference Engine, to calculate and print mathematical tables. He had formulated its principles on paper and had constructed models of some of its parts[2]:

> I endeavoured to explain the nature of the calculus of functions, and I proposed means of solving a variety of functional equations containing only one variable quantity. My subsequent enquiries have produced several new methods of solving these, and much more complicated functional equations, and have convinced me of the importance of the calculus, particularly as an instrument of discovery in the more difficult branches of analysis. (Babbage 1816:179).

Curious and tireless traveller, in the summer of 1821, with Richard Jones (1790–1855) and John Herschel (1792–1871),

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✉ Carla Petrocelli
  carla.petrocelli@uniba.it

1 Dipartimento di Studi Umanistici (DISUM), Ricercatore Universitario, Università degli Studi di Bari Aldo Moro, Bari, Italy

[1] The explanation could go back to the fact that, although Babbage was born on December 26, 1791, the registration of his birth certificate is dated January 6, 1792. (Anon. 1871).

[2] In 1815, Babbage had already published the first part of his article "An essay towards the calculus of functions", which appeared in the Philosophical Transactions of the Royal Society of London (Babbage 1815). This earned him immediate election to the Royal Society. Charles Babbage devoted many years of his long and productive life to the realization of his dream of mechanical calculations. After many years, he surrendered: although his principles were sound, the time and cost of construction proved greater than Babbage could afford. The government, which initially provided financial support, was unwilling to complete the project. (Collier and MacLachlan 1998:10).

inseparable friends since his university days, Babbage undertook a trip to Paris where he met the most important French scientists of the time: Arago (1768–1853), Laplace (1749–1827), Biot (1803–1850), Fourier (1768–1830), but he was also lucky enough to meet the German naturalist Alexander von Humboldt (1769–1859) who lived in the French capital at the time. Herschel and Babbage continued their journey to the south, going as far as Turin to meet the astronomer Giovanni Plana (1781–1864). From Milan, they returned home bending towards Lago di Como, Lago Maggiore and the Passo Sempione, then passing through Switzerland. The two friends, who always travelled with a complex apparatus of scientific instruments, never missed the opportunity, wherever they went, to make measurements and barometric measurements of altitude and temperature, filling entire notebooks with geological and mineralogical observations (Buttman 1987:38–39). Here too the script was respected so much that, on their return, they published a document, *Barometrical Observations Made at the Fall of the Staubbach* (Herschel and Babbage, 1822), based on surveys carried out at the Staubbach Falls in the Lauterbrunnen Valley, Switzerland.

For several days, the two scientists had in fact carried out accurate measurements both along the stream and upstream of the waterfall with the aim of determining whether the altitude could be defined only by looking at the barometric pressures. The richness of details, the abundance of notes and clarifications regarding the experiments, conducted separately by the two scientists and then compared, already gives a precise indication of the meticulous character of the young Babbage, who was only twenty years old at the time. He even gave a detailed description of the places where he had conducted the experiments: he emphasized their beauty and extraordinary morphological characteristics by indicating to the reader what was the best point from which to enjoy "the finest view of this beautiful cataract."[3] (Herschel and Babbage 1822: 224).

Although they could not draw acceptable conclusions, for Babbage and Hershel the trip was, anyway, a scientific success:

> There are some circumstances attending the observations at the foot of the great fall, which seem worthy the investigation of other travellers who may visit the magnificent valley of Lauterbrunnen, and who may have more time than we had for the inquiry. (Herschel and Babbage 1822: 224)

The study of geology had interested Babbage from a young age so much that, in the years following his degree in mathematics in Cambridge in 1814, he had visited interesting places in both Cornwall and Devon, almost always accompanied by his friend Hershel and often by his young wife Georgiana,[4] who, as she would continue to do in the future, took advantage of the trip to have a holiday (Collier and MacLachlan 1998:29). In the late eighteenth and early nineteenth centuries, British geologists began to ask questions about the nature of the earth, the origin of mountains, the mechanisms of erosion and the processes of extinction. The main concern of many of them was the reconstruction of stratigraphic sequences to make them the basis for a true geo-paleontological history of the Earth. Theories had been formulated and proposed in an attempt to give an interpretation of how the phenomena that changed the Earth's surface had occurred.[5]

One of the greatest proponents of the new dating of the planet was the Scottish geologist Charles Lyell (1797–1875), a friend of Babbage's, who, in his *Principles of Geology* of 1830 (Lyell 1830–33), had set out the idea that all the characteristics of the Earth's surface were the result of completely natural events that occurred over long periods of time. For Lyell there were explanations, which contrasted with catastrophic theories, leading to the conclusion that the Earth must be very ancient because of the slow succession of these daily processes. Just like his friend Babbage, between May 1828 and February 1829, Lyell had conducted trips to France and Italy, thanks to which he was able to demonstrate his principles.[6]

The *Principles* caused a stir and rekindled controversy, brilliantly centred the Scottish geologist's intentions, and was fundamental to Darwin (1809–1882) himself: "I had brought with me the first volume of Lyell's *Principles of Geology*, which I studied attentively; and the book was of the highest service to me in many ways. The very first place which I examined, namely St. Jago in the Cape de Verde islands, showed me clearly the wonderful superiority of Lyell's manner of treating geology, compared with that of

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[3] Babbage uses the term "cataract" to diversify this riverbed, which is divided into numerous small jumps alternating with rocky overhangs, by the typical waterfall which, although originated from a process of erosion, has a single, large waterfall.

[4] On 2 July 1814, Charles Babbage married Georgiana Whitmore (1792–1827) in Teignmouth against the wishes of her father Benjamin Babbage. He thought it highly improvident for Charles to marry before he was earning a good living (Hyman 1985:31–46).

[5] The most comprehensive reconstruction of this debate is provided in (Rudwick 2008).

[6] Mostly interested in volcanic areas, he had arrived in Italy at the end of August 1828 and in Naples on October 23 where he stayed until the 16th of November and then continued on to Sicily. (Rudwick 1969:288–304).

any other author, whose works I had with me or ever afterwards read."[7] (Darwin 1858:77).

In those years, Babbage embarked on his first long journey to Italy. The whole of 1827 had been a devastating year for him: in February his father Benjamin had died, on July 26 he lost his second son, Charles Whitmore, and on September he had to suffer the death of his beloved Georgiana, at only 35 years old. Because of his precarious state of health, a direct consequence of these bereavements, aggravated even more by the apparent futility of his efforts in building his *Difference Engine*, he "was recommended by his medical advisers to travel on the Continent". (Babbage 1864:72).

To recover some semblance of peace of mind, he embarked therefore on a tour of Europe. Though he wished to travel alone with and no desire to be served by a valet, his mother insisted that he was accompanied: so Charles chose one of his mechanics, Richard Wright, to travel with him as a colleague. The two men crossed the Channel near the end of 1827. Before they left, Babbage instructed his banker to make £1000 available to John Herschel, who would superintend work on the *Difference Engine* while he was away. With his companion he crossed Holland, Belgium and the western part of Germany, then heading south: from Frankfurt to Munich, until reaching the Passo del Brennero and at last he spent a few days in Venice. In Florence, he met the Grand Duke of Tuscany, with which he maintained contact in the following years.[8] "I have never been so fortunate as to be *conscious* of having experienced the least shock of an earthquake, although, when a town had been destroyed in Ischia I hastened on from Rome in the hope of getting a slight shake. My passion was disappointed, so I consoled myself by a flirtation with a volcano." (Babbage 1864:214).

The autobiography of Charles Babbage offers us numerous testimonies of his passion for scientific investigations but also of his great attention to Italy. Singular and detailed is the story of his reckless descent into a crater of Vesuvius, a volcano that at that time was in a state of "moderate activity". To observe the action of the molten lava, "I made arrangements to economize my strenght using horses or mules to carry me wherever they could go. Where they could not carry me, as for instance, up the steep slope of the cone

of ashes, I employed men to convey me in a chair." (Babbage 1864:216) Despite the contrary opinion of the guide, who saw him encumbered in his movements because of Troughton's heavy barometer ("looking much like Cupid's quiver"), by a sextant and three thermometers, he dropped down to a few meters from the glowing lava, intrigued by the bright red that shone deep down. He also used the numerous containers he had brought with him to collect mineral samples and the inevitable notebooks to take note of the observed phenomena:

> Having collected a few mineral specimens, I have applied myself to observe and register the eruptions on the little embryo volcano at the further extremity of elliptical plain. These periodical eruptions interested me very much. I proceeded to observe and register them, and found they occurred at tolerably regular intervals. At first, I performed this operation at a respectful distance and out of the reach of the projected red-hot scoria. But as I acquired confidence in their general regularity, I approached from time to time more nearly to the little cone of scoria produced by its own eruptions. (Babbage 1864:219-220)

Babbage went so far down into the crater, and stayed there so long, that his shoes nearly melted: "I would gladly have remained a longer time, but the excessive heat, the noxious vapours, and the warning of my chronometer forbade it. […] On my return to Naples I found that a pair of thick boots I had worn on this expedition were entirely destroyed by the heat, and fell to pieces in my attempt to take them off." (Babbage 1864:221–222).

A few days after visiting the Vesuvian area, Babbage went to Ischia and Pozzuoli to respectively study the effects of a recent earthquake and to observe what consequences the numerous sismic events on the Temple of Serapis had generated. Lyell, like Babbage, had visited the Temple of Serapis in 1828 and was greatly intrigued by it (Rudwick 1969:291); both had dwelt on the peculiar circular signs and mysterious holes that were evident to their eyes on the columns of the Temple (which in reality was nothing more than a *macellum*, a Roman structure used as a public market).

Although it was built above sea level, the columns of this building bore visible signs of erosion and water damage that testified its partial immersion in past years. The two scientists were attracted by these strange phenomena and felt obliged to provide an explanation: the signs and holes left by the molluscs on the marble of the columns were clear evidence that the monument had not always been at the same level as the sea and that it was the ground itself (and not the sea), with everything on it, that had risen and lowered over time.

Babbage's considerations, moreover, constituted elements of novelty also for Lyell himself, so much that Scottish

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[7] Darwin's mentor, John Stevens Henslow (1796–1861), had recommended with him to take the first volume of the Principles of Lyell and to consult it during the journey, "but on no account to accept the views therein advocated". (Darwin 1858).

[8] With Leopold II (1797–1870), Babbage began to reflect on the condition of science in Italy, noting that the greatest obstacle to scientific progress was the intellectual isolation with which each scientist developed his research. As he recalls in his autobiography, Babbage suggested setting up periodic and itinerant scientific meetings between the various Italian cities to avoid this isolation, something that the Grand Duke of Tuscany began to do in 1839, starting with the city of Pisa. (Babbage 1864:430–431).

scientist maked use of the notes derived from his observations "in the field" and the finds he had brought with him: by taking fossil incrustations, Babbage had examined the cliff inside the Temple and recorded enough data to allow him to write a small volume that he published seven years later. "The result of this survey led me in the following year to explain the various elevations and depressions of portions of the earth's surface, at different periods of time, by a theory of the earth's isothermal surfaces." (Babbage 1864:464).

In truth, Babbage's reflections attracted so much attention that they were widely circulated: he had addressed to William Henry Fitton (1780–1861) an abstract which had been read on March 12, 1834 at the Geological Society in London. From this moment on and until 1847, the year in which the book *Observations on the Temple of Serapis, at Pozzuoli*[9] was published, this essay was reprinted in specialized scientific journals: in 1834, at the suggestion of the American naturalist Benjamin Silliman (1779–1864), it appeared in the pages of the *American Journal of Science*.[10] In Germany he was given space on geologist Karl von Leonhard's (1779–1862) *Neues Jahrbuch für mineralogie* (von Leonhard 1833:347) and in 1838 it appeared in the Appendix to Gideon Mantell's *Wonder of Geology* (Mantell 1838:84–87). Indeed, a few months earlier, it was Babbage himself who reproduced it in his *Ninth Bridgewater Treatise* (Babbage 1837:209–224) accompanied, for the first time, by some figures, tables and data reported with a scientific rigour used for the description of his Difference Engine.[11]

In these contributions, Babbage attributed the changes in altitude of the soil to the action of heat: "Its own hot springs, its immediate contiguity to the Solfatara, its nearness to the Monte Nuovo, the hot spring at the Baths of Nero on the opposite side of the bay of Baiae, the boiling springs and ancient volcanos of Ischia on one side and Vesuvius on the other, are the most prominent of a multitude of facts which point to that conclusion".(Babbage1847b:20).

Fig. 1 "Temple of Jupiter Serapis", used by Lyell as the frontispiece to the first six editions of his *Principles of Geology*

Also Charles Lyell, as said before, visited the Serapeo asking himself the same questions as the mathematician of Cambridge and showing, like Babbage, that he knew how to integrate well the general physical theories with those data that he had collected and selected.[12] Choosing it for the frontispiece of his *Principles of Geology* of 1830, Lyell transformed the image of the Temple into one of the most famous and evocative scientific representations of the nineteenth century, an emblem of a time that was ready to finally welcome the "new science".

The three columns and the floor invaded by water showed, evident, the signs left by the barnacles; all the other architectural components, including the ruins behind the columns, assumed, from this moment, almost an accessory role. Charles Lyell, a man of vast culture and acute historical

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[9] In 1834, the work entitled "Observations on the Temple of Serapis at Pozzuoli near Naples" was read by the Geological Society of London (Babbage 1834) and republished by the Geological Society in 1838 (Babbage 1838); Babbage did not agree to its publication until 1847 (Babbage1847a) and then with an edition in which a brief integration of the data collected at Pozzuoli appears (Babbage1847b).

[10] In the section *Rise and Decline of the Metamorphic Theory of Granite*, Babbage is cited for being the one who had launched the idea of the aqueo-igneous fusion: "The germ of this idea of aqueo-igneous fusion was far older, due to Babbage and John Hershel, neither of them geologists, but such sweeping extensions of it had never before been published." (Anon. 1918:144).

[11] As (Dolan 1998:315) reported, "Babbage illustrated the uniform and gradual actions of the earth the same way he illustrated the uniform and gradual actions of his calculating engine. Both were approached with a shared concern over accurate and efficient methods of representation in science".
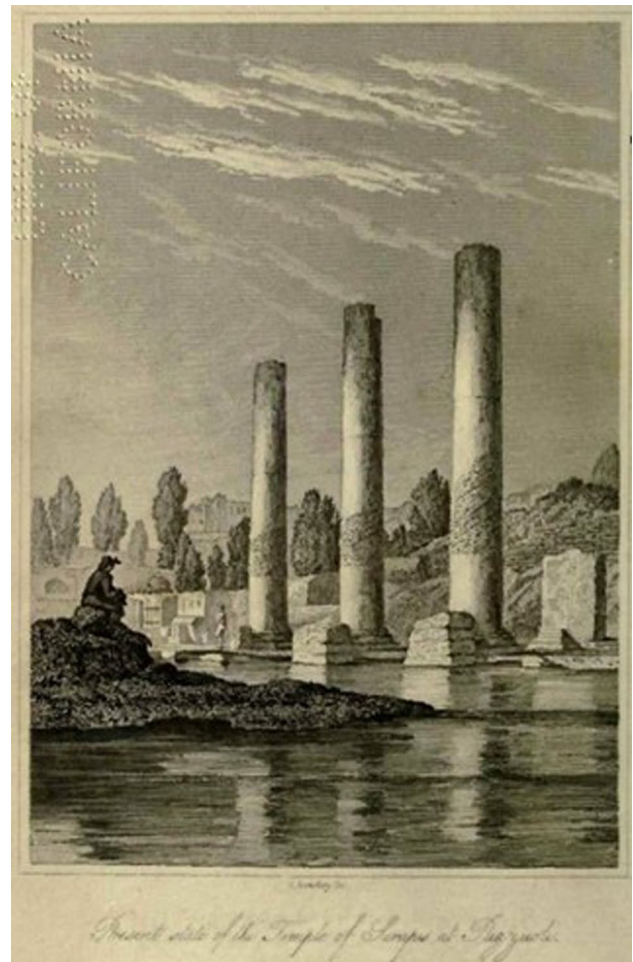
[12] Lyell visited the Serapeo area on November 12, 1928, a few months after Babbage. (Dolan 1998:302).

sensitivity, probably chose them with the awareness of his great evocative power (Fig. 1).

In some of his letters and in his reflections on the Temple, it is evident how much Lyell took Babbage's opinion into consideration: the sketches and precise measurements of the latter proved invaluable to the geologist who, in a letter dated January 5, 1833, asked again his English colleague "all the plates on that region which you let me have last year, and which I was unable then to make use of". Aware of the fact that the English friend had visited and studied the site in depth, Lyell often asked his opinion on some hypothesis he had made: "I should like to show you Sir W. Hamilton's plate of the place where I think you found the serpulae on the cliff south of Puzzuoli, to ask if am right". (Lyell and Lyell 1881:395).

2 The *Difference Engine* as a geological "tool"

The data collected were compared, processed and reported by Babbage who used his famous calculation machine, designed from 1821 and built only for a small part of it until 1834, when he decided to venture into the construction of a new device, the *Analytical Engine*, to allow a broader programming, not strictly related to the calculation and printing of mathematical tables. (Cfr. Collier and MacLachlan 1998: 73–83).

The great desire to manipulate error-free data, the result of complicated mathematical calculations, strongly characterized the life of the English scientist who always had the constant impulse to use instruments of absolute reliability. In addition, his maniacal precision led him to perfect those processes that involved the mechanization of printing, technical drawing and graphic design, tools that, among others, allowed him to provide an explanation of geological phenomena and the activities of the earth and to do so in an exclusively experimental way. (Campbell-Kelly 1988:163–165) The measurements, diagrams, drawings, calculations made on site, added to the fragments taken from the Temple area, the averages of water and air temperatures recorded meticulously, represented in fact a solid input data base for his *Difference Engine*.[13]

Supported by studies published by the American engineer William Bartlett (Bartlett 1832) that illustrated the consequences of heat on the expansion of certain types of stones, Babbage supported his arguments on the effects of an underground heat source as a cause of expansion and contraction of rocks. The results obtained through his *Difference Engine* showed the expansion of rock masses of granite, marble or sandstone, with thickness that could vary from 1 to 500 miles, subjected to different degrees of heat ranging from 1 to 3000 Farhenheit. (Babbage 1837:198) (Fig. 2).

Babbage concluded that the ground on which the Temple had been built, which was near the sea and therefore mostly sandstone, could have been raised 25 feet (i.e. about 7.62 m) if it had been subjected to a temperature rise of 100°F for a 10-mile stretch (about 8 km). (Babbage 1847a:207) Exactly with the aim of providing experimental evidence "of the changes which have continually taken place in the forms and levels of the large portions of the earth's surface at many different periods of time, and which appear still to continue their slow but certain progress" (Babbage 1847a:206), Babbage correlated different temperatures with the conductivity of rocks. Excessively concentrated heat caused cracks in the soil layers bringing out volcanic eruptions during which liquefied materials and gases were displaced. The latter could be linked to the occurrence of earthquakes and help to cool the rocks, with their consequent contractions. And therefore, temperature changes caused by a new heat release from some surrounding volcano, which raises the temperature of the rock beds again, followed by slow contractions as the soil cooled, had caused the Temple's surface to rise and contract.

Generalizing these demonstrations, Babbage also dared an explanation of the rise of the mountain ranges, the subsidence and the elevation of the coasts. Again, to explain the gradual sinking and subsequent elevation of the land, he focused on the effects of underground heat sources which, in his opinion, would cause gradual and uniform changes in the earth's crust. In fact, Babbage believed that the elasticity of the earth's crust was an intrinsic quality, made possible by the action of an "elastic fluid" such as heat, capable of modifying the rigidity of the rocky masses. He presented a large number of measurements, diagrams, illustrations and calculations to advance his proposal that the earth's heat would increase with depth and be evenly distributed from a central core (earth's heat source) to the earth's surface. (Cfr. Dolan 1998:299).

His was a comprehensive and innovative account on how gradual and uniform geological actions could explain soil subsidence and elevation.[14] The use of the concept of

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[13] It is quite clear from his correspondence that these data were taken from the blocks on which he had noted the measurements during his visit. (Babbage 1847a).

[14] These deductions by Charles Babbage influenced the theories advanced by Henry Darwin Rogers (1809–1866) to explain the elevation of the Appalachian Mountains that he presented in a paper read to the American Association of Geologists and Naturalists in April 1842, one of the most important American contributions to theoretical science before 1850. Rogers argued that the mountain ranges were formed as a result of movements caused by a rippling of the crust that occurred because the molten matter beneath pulsed or moved in a wave-like motion. On his trip to England, Rogers had the opportunity to gain access to the London Geological Society and to meet "several of the members, De la Beche, Lyell, Babbage and others." It is Babbage that he dwells on in a letter to his brother William dated 14 Feb.

Miles in thick-ness.	Degree of Fahrenheit's Scale.							
	1.	20.	50.	100.	200.	500.	1000.	3000.
1	·0255	·510	1·275	2·55	5·10	12·75	25·5	76·5
5	·1274	2·548	6·370	12·74	25·48	63·70	127·4	382·2
10	·2548	5·096	12·740	25·48	50·96	127·40	254·8	764·4
15	·3821	6·642	19·105	38·21	76·42	191·05	382·1	1146·3
20	·5095	10·190	25·475	50·95	101·90	254·75	509·5	1528·5
25	·6369	12·738	31·845	63·69	127·38	318·45	636·9	1910·7
30	·7642	15·286	38·215	76·43	152·86	382·15	764·3	2292·9
35	·8917	17·834	44·585	89·17	178·34	445·85	891·7	2675·1
40	1·0190	20·380	50·950	101·90	203·80	509·50	1019·0	3057·0
45	1·1464	22·928	57·320	114·64	229·28	573·20	1146·4	3439·2
50	1·2738	25·476	63·690	127·38	254·76	636·90	1273·8	3821·4
55	1·4012	28·024	70·060	140·12	280·24	700·60	1401·2	4203·6
60	1·5286	30·572	76·430	152·86	305·72	764·30	1528·6	4585·8
65	1·6559	33·118	82·795	165·59	331·18	827·95	1655·9	4967·7
70	1·7833	35·666	89·165	178·33	356·66	891·65	1783·3	5349·9
75	1·9107	38·214	95·535	191·07	382·14	955·35	1910·7	5732·1
80	2·0381	40·762	101·905	203·81	407·62	1019·05	2038·1	6114·3
85	2·1655	43·310	108·275	216·55	433·10	1082·75	2165·5	6496·5
90	2·2928	45·856	114·640	229·28	458·56	1146·40	2292·8	6878·4
100	2·5476	50·952	127·380	254·76	509·52	1273·80	2547·6	7642·8
200	5·0952	101·904	254·760	509·52	1019·04	2547·60	5095·2	15285·6
500	12·7380	254·760	636·900	1273·80	2547·60	6369·00	12738·0	38214·0

Fig. 2 Table showing expansion of granite (ft) from 1 to 500 miles thick when heated to various temperatures, which, as Babbage pointed out, was computed by the *Difference Engine* (Babbage1847a:32)

heat distribution, combined with rock expansion calculations performed with extreme precision using his machine, not only provided new hypotheses and explanations of the "anomalies" of the columns of the Temple of Serapis, but contributed to the development of a "calculating culture" that was also useful for analysing geological phenomena. (Dolan 1998:302).

In his writings and correspondence, Babbage has repeatedly stressed that unusual or abnormal events, apparently occurring in nature, explained as miraculous events, should instead be attested through mathematical principles and rules.[15] As mentioned earlier, both in the *Ninth Bridgewater*

Footnote 14 (continued)

1833, in which he admits: "none so awakened my admiration as Babbage." (Gerstner 1975:26; 32–36).

[15] Early in 1832 Babbage wrote a public letter to David Brewster (1781–1868), "On the Advantages of a Collection of Numbers, to be Entitled the Constants of Nature and Art." In this letter he proposed that it "would be of the greatest advantage to all classes of the scientific world" if the various united academies would collect and publish "all those facts which can be expressed by numbers." He indicated the need for data about subjects such as the following: astronomy, atomic weights, chemical compositions, metals, mammalia, vegetables,

and in his *Observations on the Temple of Serapis*, in an attempt to take into account geological changes, Babbage proposed demonstrations based on precise calculations. His answer was that discrete and abnormal changes could be generalized according to strict laws, provided that the chronological framework on which to base them was sufficiently broad. The English mathematician believed that "the gradual advance of Geology, during the last 20 years, to the dignity of a science, has arisen from the laborious and extensive collection of facts, and from the enlightened spirit in which the inductions founded on those facts have been deduced and discussed. To those who are unacquainted with this science, or indeed to any person not deeply versed in the history of this and kindred subjects, it is impossible to convey a just impression of the nature of that evidence by which a multitude of its conclusions are supported." (Babbage 1837:47) As Dolan argued, this idea implied that the physical sciences could say more about natural laws than previous divine revelations or sudden, unexplained catastrophes: geology, therefore, became a "method" that involved experimentation and accurate representation. (Dolan 1998:314–315).

3 Still in "the country of Archimedes and of Galileo"[16]

In 1840, Babbage made another journey to the continent. In Lyon, France, he visited a silk-weaving plant that was using Jacquard looms. He watched in great fascination as the loom with 24,000 punched cards automatically generated a very fine portrait of the inventor, Joseph Jacquard. This was the ingenuity of the punched-card system of control that Babbage used for his *Analytical Engine*. (Babbage 1864: 306).

Babbage continued his trip to Turin to attend the second congress of Italian scientists where he spent much time describing his *Analytical Engine* to Italian mathematicians. In 1841, in Florence he was awarded the Great Cross of the Order of Merit by Leopold II, Grand Duke of Tuscany, a recognition for his scientific commitment.[17] On this occasion,

he had the opportunity to visit the area of the *Boracic acid of Larderello*, called *Lagoni di Monte Cerboli*, which showed to his eyes all their scientific potential. The interest in natural phenomena and the amazement that this place left in his soul as a researcher, pushed him to write a report for the Grand Duke of Tuscany to suggest the exploitation of those "infernal emissions" to operate the large steam engines used in the nascent industry sector.

Fascinated by the beauty of the site, just as he did during his trip to Switzerland at a young age, Babbage proposed a very detailed description of these places:

> The district in which the Lagoni occur is one of the most singular countries in the world. Near the village of Monte Cerboli, in the midst of a deep rugged and broken ravine, is one of the eight establishments for extracting boracic acid from the earth. From the whole surface of a large space, probably a square mile of the broken ground, there issues a large volume of steam, which rises high in the atmosphere before it is absorbed, and may be seen at the distance of many miles. In the midst of this fog of steam, on a small plain forming a kind of island, stands a village containing the cottages of the workmen, the evaporating-chambers, the storehouses, and a church recently built. The process of preparing the boracic acid is the following: on excavating a few inches into any part of the broken ground steam issues with great force, driving with it mud and even stones with a violent noise. [...] These works are now in the sagacity of the Chevalier Larderel, now Count of Le Pomarance that conceived the happy idea of employing the heat which nature so plentifully offered, and thus dispensed with the whole expense of fuel. The result of this plan of converting volcanic heat to commercial purposes has been the establishment of villages and a thriving population in a locality which was previously almost a desert. (Babbage 1843:178−179)

Babbage went further, proposing an exploitation of the site not only limited to boric acid extraction ["about ten years ago the whole of the borax consumed in England was imported from the East Indies; at present more than half the demand is supplied from the boracic-acid works of Tuscany" (Babbage 1843:179)], but also for the use of heat in wine production ["Heat could be applied to the produce of

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Footnote 15 (continued)

geography, velocities, population, buildings, weights and measures, dates, etc. (Babbage 1832a:338).

[16] On the frontispiece of Charles Babbage's autobiography there is the dedication of the volume to Victor Emmanuel II. The English mathematician expresses all his gratitude to the "Sovereign of united Italy, the country of Archimedes and of Galileo." (Babbage 1864) In 1840 he went on a triumphal tour of Italy and was well received for his work on the *Analytical Engine*. In his own country, however, he was unsuccessful in obtaining government support for his project and finally in 1842 they gave up all claim to his *Difference Engine*.

[17] On 18 November 1841, Babbage wrote to Leopold II: "Sire, it is difficult to express to your Royal Highness even in my native language those feelings of gratification which were excited by the interview with which you honoured me this morning. […] The Gran cross

Footnote 17 (continued)

of your order of Merit given to me by that Sovereign of Tuscany who has offered so enlightened an example of the encouragements of all that adorns and improves the highest faculty of man would be alone invaluable. But Sir I trust you have penetrated sufficiently into my heart to acquiet me of any personal vanity." (Babbage 1841:157).

vineyards to form alcohol which in turn could be the foundation of an extensive chemical industry" (Hyman1985:187)] and to generate geothermal energy ["Iron pipes inserted into the ground could yield steam at pressure which would be an unrivalled source of power" (Hyman1985:187)].

This approach clearly shows how Babbage proposed his solutions without ever neglecting the economic and practical aspects. Already in 1828 he had been dealing with what could be the relationship between mathematics, document printing technologies, and political economy. To gather the informations he needed to write his monumental book *On the Economy of machinery and manufactures* (Babbage 1832b), he visited workshops, factories, mines and production districts, both at home and abroad. The book, which "was aware he was addressing by far the largest class in this or any other country, the manufacturing class", espoused the economic principles of division of labour and was a panegyric about the virtues of mechanical production: Babbage was convinced that scientific and technological practices should conform to the principles of political economy; science and technology, instead, should coexist to be usefully used for industrial growth. As stated by the scholar Anthony Hyman, in the image of the world provided by Babbage there seems to be a close relationship between the physical particle, which moves freely but is subject to natural laws, and the commodity in the capitalist system: nature is stable and efficient, and science should apply the logic of artifacts to better understand it (Cfr. Hyman 1985:84).

The exploitation of fumarole for energy purposes still continues today: steam and hot water springs are used to spin turbine blades. One of the most important geothermal sites in the world was born in the Larderello area.

4 "Every shower that falls, every change of temperature that occurs, and every wind that blows, leaves on the vegetables world the traces of its passage"

In his *Note M*, closing the *Ninth Bridgewater Treatise*, Babbage also dwelt on the kind of information that the rings visible in the tree trunks could give about the geological ages of the Earth. In the arrangement of these rings he saw a codification of nature's own messages relating to the past. According to the English scientist, each tree records a complex set of information because "every shower that falls, every change of temperature that occurs, and every wind that blows, leaves on the vegetable world the traces of its passage; slight, indeed, and imperceptible, perhaps, to us, but not the less permanently recorded in the depths of those woody fabrics." (Babbage 1837:228).

With the aim to suggest to the reader a line of inquiry, useful to retrace a "small portion of the history of the past"

and looking at what the fossil forests reveal to us, Babbage explained that, although it was already known that "dicotyledonous trees increase in size by the deposition of an additional layer annually between the wood and the bark, and that a transverse section of such trees presents the appearance of a series of nearly concentric irregular ring, the number of which indicates the age of the tree" (Babbage 1837:227). Each ring, in fact, can be observed in more detail and can be divided into others that indicate the periods of the year when its vegetation was more or less flourishing or even slowed down. Babbage experimented that even the movement suffered by a tree due to the winds has an influence on its growth: by planting two young trees, of equal size and vigor, in similar places, and preventing any movement for the first from north to south and for the other from east to west, he recorded, after several years, that the sections of both showed oval rings but with longer axis coinciding with the direction in which theirs was allowed the movement by winds.

These indications, says Babbage, are, therefore, preserved in the fossilized trunk. He claimed that these informations, both concerning single trees and entire forests, are extremely determinant for the deductions that can be made about the fact that they have been submerged by the sea or that they are embedded in peat moss, or transformed, as in some of the hardest layers, into stone. The nature of the subsequent seasons, hot or cold, wet or dry, would be easily deduced with an acceptable degree of probability and this type of evidence, even if minimal at first, could to some extent be ascertained even in remote geological periods. (Babbage 1837:229).

Babbage dealt, therefore, with the concept of parent trees, the reconstruction of the climate and specific patterns of tree rings subject to storms and floods. He formulated his own research on the climatic response of trees and their ability to record the climate over time and, in this case too, he anticipated the times by proposing the so-called *crossdating*,[18] i.e. the process of matching ring widths to obtain exact dates of annual growth of the tree itself.

5 Nature and constants

Although he was never a member of the *Geological Society* of London, Babbage almost always participated in the meetings held there and presented many of his research. In addition to the more well known *Observations on the Temple of Serapis*, he also published *On the Actions of Ocean-currents in the Formations of the Strata of the Earth* (Babbage 1856) and some of his *Observations of*

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[18] On the origin of this term, see (Studhalter 1956:31–35).

No.	Velocity of fall per hour.	Nearest distance of deposit to river.	Length of deposit.	Greatest distance of deposit from river.
	Feet.	Miles.	Miles.	Miles.
1.	10	180	20	200
2.	8	225	25	250
3.	5	360	40	400
4.	4	450	50	500

Fig. 3 Rate at which sediment falls into the ocean (Babbage 1856:367)

the Parallel Roads of Glen Roy (Babbage 1868). In both contributions, he referred to his 1834 communication on the Temple of Serapis but in each of them he added specific considerations, respectively, to the laws governing the deposit of matter on the seabed and the morphological characteristics of the Scottish site called Glen Roy.

In the first paper, he defined general laws that indicated how the "finely divided earthy matter" due to the atmospheric conditions that act on it, was transported from the mouths of rivers to the oceans, and then moved by the currents and brought to the ocean depths. The English mathematician observed that, if we carefully study the relationships between the specific weight, shape, and size of the particles transported, we can define general rules that indicate whether the ocean currents will separate the substances that make up the debris or if, on the contrary, they will combine different substances to create new ones (Babbage 1856:366). As a demonstration of these hypotheses, he attached to the article a table in which he represented the rate of fall of the sediment into the ocean, starting from his assumption that the river, at the point of junction with the sea, had a depth of 100 feet (Fig. 3).

These infinite combinations that are generated, when the above-mentioned conditions vary, can be the cause of the raising or lowering of the seabed on which the sediments are deposited, also giving rise to disconnected masses. Babbage pointed out that in the immense period of time during which these sediments are deposited in the ocean depths, hydrographic changes could also occur or there could be new currents that add other sediments in the same area, causing a mixture with the older deposits.

In 1838 Charles Darwin visited the so-called "parallel roads" of Glen Roy, stepped terraces along the flanks of a Scottish valley. He dedicated to this subject a long essay sent to the *Royal Society* of London in 1839, *Observations on the parallel roads of Glen Roy* (Darwin 1839), in which he made a comparison between these terraces and those seen in Chile (the terraces of Coquimbo) and explained them using his theory of the lifting of the ground and the lowering of the seabed. This assumption was later contradicted by Agassiz's glacier-lake theory that the coastlines had been cut by the freezing and thawing processes of the ice. Darwin himself, in fact, in his autobiography, called this paper a "great failure" precisely because he had not taken into account the effects of glaciation (Darwin 1858:65). A few years later, Charles Babbage, realizing that an acceptable scientific explanation had not yet been formulated, resumed this discussion in his *Observations of the Parallel Roads of Glen Roy* in 1868 and claimed that these terraces were what was left of the ancient lakes that had filled the valleys: under the effect of rain, wind, snow and falling temperatures, the mountains had crumbled, creating these barriers and this unique geological conformation of the site (Babbage 1868:274–275).

A scientist, a curious genius, a tireless and bizarre traveller, even when he was involved in geology, Charles Babbage taught us that, if one undertakes a scientific journey, the collection of data and objective observation of phenomena must have absolute priority; however, any other aspect, far from pure scientific research, must never take second place, but become an element of enrichment and completion of what is proposed (Cfr. Babbage 2007:IX–X).

His disparate interests, often far removed from mathematics, were actually held together by a single thread, an obsession with precision and the correct treatment of the information he was processing. "Knowledge is power": Babbage strongly believed in the power of knowledge inferred by science. Knowledge was limitless fields for him, the lifeblood of progress, what governed the arts of life but above all science. (Babbage 1832b:297–298).

He was always looking for data, with the conviction that it was inconceivable to face a problem without having secure, certain information: every fact had to be able to be transformed into a number, as precise as possible. "The errors that result from a lack of data are much more numerous and more lasting than those that result from uncertain reasoning based on real facts", he used to say. (Babbage 1832b:131) For this reason he had proposed a machine that produced absolutely exact mathematical tables, precisely to treat those data that were now almost an obsession: from the weight of the animals to the height of the trees, from the speed of the birds to the resistance of materials, from the flow of the rivers to the deposit of sediments in the oceans. The machine had to ensure the accuracy of these numbers because, through these values, it could represent all the constants of nature, physical, chemical, mathematical, astronomical, geological, and biological. (Cfr. Purbrick 1993: 12).

In 1864, Charles Babbage printed his memoirs, *Passages from the life of a philosopher*, not an autobiography but "a variety of isolated circumstances in which I have taken part—some of them arranged in the order of time, and others grouped together in separate chapters, from similarity of subject" (Babbage 1864:VIII). Babbage can be called a "philosopher" in a different sense from the traditional one: his interest in every aspect of reality led him to "to endeavour to discover those laws of mind by which man's intellect passes from the known to the discovery of the unknown. This feeling was ever present to my own mind, and I endeavoured to trace its principle in the minds of all around me, as well as in the works of my predecessors." (Babbage 1864:486).

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