John Phillips's astronomy 1852–67, a pioneering contribution to comparative planetology

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Contemporaries were well aware of the contributions to astronomy of Professor John Phillips (1800–74), a distinguished geologist latterly at the University of Oxford. As part of his research to explain the age and physical processes of observed geological features – mountains, volcanoes, craters and rift valleys – he sought additional evidence by comparison to potentially similar features upon the Moon and even Mars. In the 1850s and 1860s by his innovative comparative method, and his systematic and collaborative approach made possible by his influential position within the British Association for the Advancement of Science (BAAS), he made a pioneering contribution to the evolving new science that in 1905 was designated comparative planetology – the study of the surfaces and atmospheres of planets and satellites instead of simply their positions.[1]

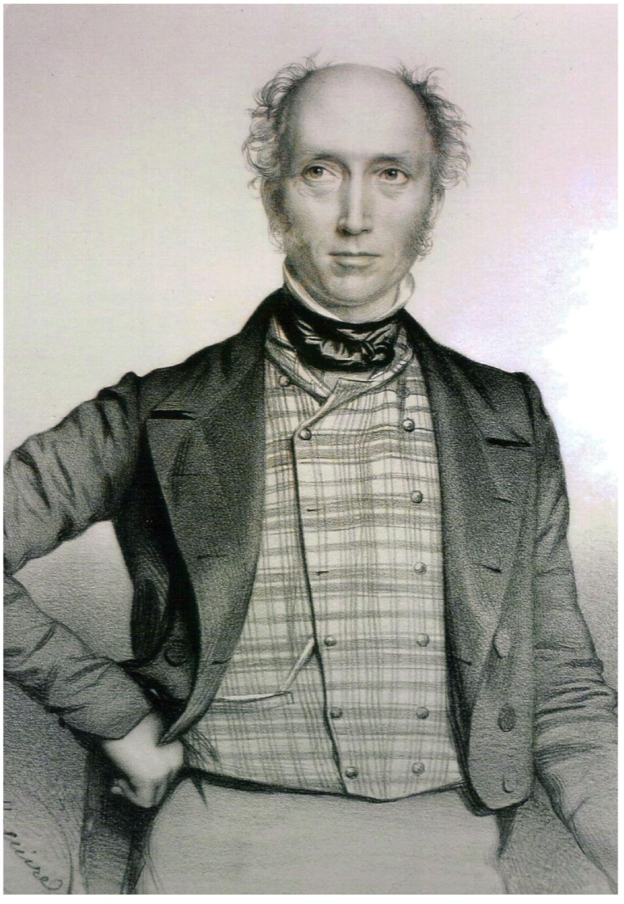

Fig. 1 John Phillips at age 51 in 1851.
Lithograph by T.H. Macguire, owned by York City Art Gallery, from a copy displayed at the Oxford University Museum of Natural History (OUMNH).

The Moon before 1874

We have enjoyed the great privilege of living through the first golden age of solar system exploration by spacecraft that began in 1959 with the first photographs of the far side of the Moon by the spacecraft Lunik III. Truly astonishing photographs of the Moon and Mars now seem routine. Therefore it is worth recalling the historical context and limitations within which Phillips and other astronomers sought to advance knowledge of the planets in the mid-nineteenth century.

Thomas Harriot (1560–1621) compiled the first telescopic map of the Moon. This was several months before Galileo in 1609 was convinced he saw mountains casting shadows, and valleys penetrated by light at different phases, and attempted to calculate the heights of the mountains. Johannes Hevelius (1611–87) published the first influential book on the Moon, *Selenographia*, in 1647. Francesco Grimaldi (1618–63) then drew maps of the Moon to illustrate his Jesuit colleague Giambattista Riccoli's *Almagestrum Novum* (1651) which provided the basis for the system of lunar nomenclature still used today. Giovanni Cassini (1625–1712) used improved telescopes to publish a much enhanced map in 1692. At this period there was a consensus that the Moon had an atmosphere, and might even be inhabited. The limitations upon observations are emphasised by the long gap until the next significant map, which Tobias Mayer (1723–62) published in 1775. It was only 7½-inch in diameter but with features carefully drawn, so remained in general use for many years. Sir William Herschel (1738–1822) made the best telescopes of his day and gave some attention to the Moon, but did not undertake systematic charting. He believed that active volcanoes existed on the Moon, and his drawing reproduced in the *Encyclopaedia Britannica* of 1797 is historically important.

Johann Schröter (1745–1816) acquired a Herschel 7-foot reflector of 6½-inch aperture and made an intensive study of the Moon. He discovered a large number of previously undetected small craters and rills, introduced a new method of calculating mountain heights, and tried to detect an atmosphere, its height, and effect on lunar twilight. He laid the foundations of modern selenography. William Beer (1797–1850), a banker, purchased one of the new and vastly improved 3¾-inchFraunhofer equatorial refractors which had a sharper definition than the reflectors used by Herschel and Schröter, set it up in an observatory, and from 1830 Johann von Mädler (1794–1874) used it to undertake an exhaustive survey of the Moon. In 1834 they published a map in four sections each 20 inches square, together with a descriptive volume *Der Mond*. They indicated the position of 7,735 craters, gave exact positions for 919 features, and the height of 1,095 mountain peaks. Most observers concluded that further such detailed research was a waste of time, so that theirs became the standard map for several decades. However, scope remained for initiatives in specialised research. Julius Schmidt (1825–84) began a 40 year study, and in 1866 he alleged change in the crater Linné suggestive of active processes at work. James Nasmyth (1808–90) and his friend James Carpenter (1840–99) used Nasmyth's famed 20-inch reflector to prepare drawings and make very precise plaster models of small portions of the lunar surface which they placed in bright sunlight and photographed. The resulting beautiful plates published in their book *The Moon* in 1874 were finer than any direct photographs being produced by other observers with a variety of telescopes and the new dry plate technology. It was within this challenging field of investigation that John Phillips made his contribution. Early in his researches he also considered what Mars might yield.

Elusive Mars

Mars was the only other planet that might yield knowledge regarding its surface. An excellent modern history of the slow accumulation of knowledge of Mars is Bill Sheehan's work (1996).[2] Summarising the difficulties of observing its tiny disc, and the tantalising glimpses of markings seen by some observers, Sheehan summarised that the drawings made prior to 1830 'are rudimentary and give no real idea of the physical constitution of the planet'.[3] The long focal-length refractors of the seventeenth century enabled Christian Huygens to approximate the diameter of Mars and its distance from Earth, and to record a south polar cap. In 1777 William Herschel began systematic observations of Mars at oppositions. He did not attempt maps, but after observing the opposition of 1781 announced that he had detected a second polar cap and believed that they were composed of ice, determined a rotation and deduced an axial tilt. By 1783 the new 12-inch speculum mirror for his 20-foot telescope enabled him to observe seasonal colour variations, and in 1784 he reported to the Royal Society that from these changes he believed Mars has a substantial atmosphere with clouds. Herschel had concentrated on determining the physical data for Mars, and the elusive dark markings were of incidental interest.[4] Supplemented by the work of Johann Schröter a tentative start had been made on Martian geography.[5] The next advance was made possible by the dramatic improvement in refractors – gradually larger achromatic object glasses and shorter focal lengths. Beer and Mädler together used their 3¾-inch Fraunhofer to observe the 1830 opposition. They concluded that the surface markings were permanent, and identified a feature suitable as a reference point for determining rotation, which was later adopted as the prime meridian. The 1836–37 opposition, and access to the 9.6-inch refractor of the Berlin Observatory, enabled them to add significant detail, including for both polar caps.[6] In 1840 Mädler drew the first map of Mars ever made. Despite its limitations to only the more conspicuous features, it represented a great advance. The wider availability of larger refractors, despite Mars being too southerly in 1860, subsequently attracted efforts to study the surface by several skilled observers. These included Frederik Kaiser (1808–72) – with 7-inch Merz refracttor, Angelo Secchi (1818-78) – with 9½-inch Merz refractor, John Phillips – with 6-inch Cooke refractor, and Norman Lockyer (1836-1920) – with 6¼-inch Cooke refractor, who all during the opposition of 1862 and the especially favourable opposition of 1864 scrutinized the surface. In particular, William Rutter Dawes (1799–1868) observed in November 1864 to January 1865 with an 8-inch Cooke refractor bearing 258 and greater magnification and produced drawings of unsurpassed detail. Beer and Mädler's map was by 1862 out of date, and the increased number of features required names instead of the old lettering. That state of lunar and Martian studies is the context for Phillips's initiatives in 1852–67.

John Phillips as scientist

John Phillips was primarily a geologist. He was born on Christmas Day 1800 in Wiltshire, orphaned at the age of seven, and then was brought up by his uncle, William 'Strata' Smith (1769–1839) later dubbed the 'father of English geology'. Phillips left school at fourteen, then went on to receive a thorough practical training as surveyor and geologist from his uncle, and helped him prepare his county maps. By 1825 he was a lecturer, an acknowledged expert on Yorkshire geology and fossils, and was appointed Keeper of the Yorkshire Philosophical Society's museum. In 1831 he was a founder of the British Association for the Advancement of Science (BAAS), and recognized as its driving force through his office of Assistant General Secretary 1832–62. His administration of meetings and editing reports for their Journal gave him a wide network of connections and influence. In 1834 he was appointed Professor of Geology at King's College, London, and elected to the Royal Society. The British Association's 'growth and progress [was] dependent on the energy which [Phillips] threw into its business and the genial feeling he so successfully diffused among its members'.[7] The BAAS Reports and his own published research show that he constantly worked on his own, but devised methods and programmes for cooperative efforts for measurements and observations in meteorology, meteors, and magnetic phenomena. His original researches and constant committee work established his influence.

Phillips had developed a new method of research, statistical palaeontology – analysing the number and distribution of different fossils within strata – and comparison of survey results as he sought explanations by physical processes for the flexing, fracturing, and mingling of strata. Now with a national reputation, in 1841 his monograph *Palaeozoic Fossils* proposed that there were three great periods of past life on earth called the Palaeozoic, the Mesozoic, and the Cainozoic, terms still used over 150 years later.

Phillips's lunar work at York, 1852–53

Because Phillips was a polymath whose astronomy was one of the least of his achievements, it has been largely overlooked. Of nine biographical notes, only two credit him with one of the first two wet collodion photographs of the Moon, and only one, in 1974, offered a concise note on his lunar work.[8] In contrast to the importance Phillips gave to his astronomy, the neglect of it by biographers reflects that his work on the Moon, Mars and the Sun was swiftly overtaken after his death in 1874 by rapid technological progress in astronomy – much larger aperture telescopes with excellent driving clocks, and dry plate photography.

John Phillips began his astronomy before the mid-century when telescopes with excellent 5 and 6-inch object glasses and improved micrometers were becoming more affordable, and made possible really useful research. The prestigious Gold Medal of the Royal Astronomical Society (RAS) was awarded to several astronomers who made discoveries with such instruments. The construction of the Earl of Rosse's great 72-inch reflector in 1845 caught the widest interest, as also did the discovery of Neptune in 1846. Astronomy as the first applied science enjoyed prestige within a hierarchy of science organized by sections in the BAAS.

Since 1833 Phillips had the use of the York Philosophical Society's (YPS's) new observatory, and he befriended Thomas Cooke (1807–68) who became a telescope maker.[9] In 1839 as Keeper of the YPS's Museum he moved in to St Mary's Lodge within its grounds. He observed Mars and the Moon with his own 2.4-inch Cooke refractor, and he particularly sought detail of the lunar 'walled plains' (which we now know to be impact craters, a theory not available to him). He studied the lunar surface features and compared them to those he knew on Earth in order to try and understand their geology.

By 1852 'Astronomy largely engaged his attention'.[10] Appreciating the availability and variation of instruments, their location and climate, the visual acuity and artistic skill of different observers, their different interests and experiences, all led Phillips to conclude that to explain the visible features of other worlds his own experience could not suffice. The problems of astronomy necessitated collating and comparing data. This fitted well with the BAAS ethos of organized collaborative research effort in pursuit of scientific knowledge. His plans of 1852 for a new selenography were devised to minimize the difficulties of the variability of observations. His new method was for several observers to observe designated features at different times of the lunar day, and at different phase angles of the lunar month. In this way the detection and careful micrometer measurement of the smallest features revealed by changing light and shadow would enable new geological information to be reliably compiled. His observing log and published papers show that he applied the same comparative technique for Mars and the Sun. In astronomy his own observing skills, his ability to motivate and organize, and his scrupulous and generous acknowledgement of the work of other astronomers spread over decades won their respect.

At the BAAS Meeting of 1852 Phillips drew the Association's attention to the fact that Beer and Mädler's maps of 1834 and 1836 were now out of date.[11] Phillips proposed not a lunar chart, but to ascertain whether a number of observers coordinating detailed observation of lunar areas might determine their origin by comparison to geologic features on Earth. The proposal resulted in:

> Recommendations adopted by the General Committee at the Belfast Meeting, September 1852, that the Earl of Rosse, Dr [T. Romney] Robinson [of Armagh Observatory], and Professor Phillips be requested to draw up a report on the physical character of the Moon's surface as compared to that of the Earth.[12]

A new sub-committee was formed with Phillips as Secretary, and he invited fourteen observers in Britain and abroad known to have adequate instrument power to each observe a designated area. Phillips started work with Lord Rosse's 36-inch and then the great 72-inch reflector. The latter produced: 'A six inch image of extraordinary magnificence so that features of seventy mile diameter were visible with the naked eye, at 1000 power features of 370 feet could be seen but not defined'.[13]

Phillips thus sought to define the smallest features visible that could be observed and drawn. In 1853 he co-authored with Rosse a guide 'On the Physical Character of the Moon's Surface, as compared with that of the Earth'. However, the images in Rosse's great reflectors were too bright for fine detail, the telescopes were not equatorial, and the drawing position was too uncomfortable. Therefore he had persuaded Thomas Cooke in 1852 to lend him a splendid new 6¼-inch refractor of eleven feet focal length, which was set up in Phillips's garden in York.[14] He used it in the open air: 'and completed a sketch of his appointed region on 19 May 1853, thus establishing the facility of carrying out the desires of the Committee'.

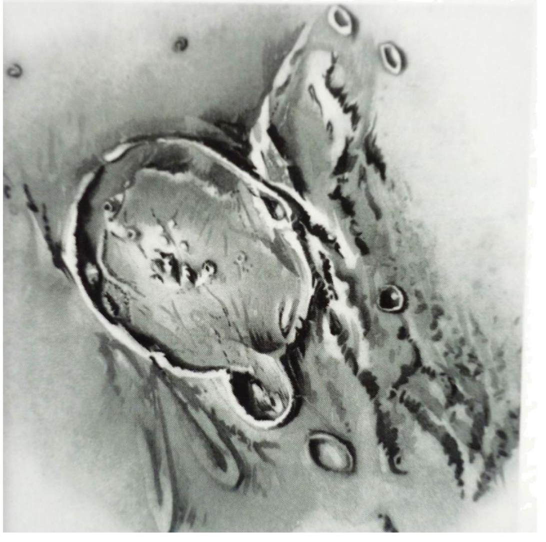

Fig. 2 Lunar Crater Gassendi, 1852.
John Phillips, 'Notices of some parts of the Surface of the Moon', *Phil. Trans. R.S.*, 158 (1868), 333-46.
Photo courtesy of Stella Brecknell, OUMNH

Then to maximize his proposal to the BAAS's next meeting, he worked to present photographs made with the same telescope to compare to his drawing of fine detail in the crater Gassendi. In July 1853 he experimented with the new wet collodion Talbot-type process invented in 1850. On 18 July 1853 his Moon Photo No. 2 taken with 26 magnification 'impressed an image 1¼″ on the collodion in five minutes'.[15] He sent this photograph promptly to his friend Edward Sabine (1788–1883), Secretary of the Royal Society, but apparently did not seek to exhibit it before the forthcoming BAAS meeting in Hull in September. At that meeting Phillips read an elaborate paper on the subject. He stated that 'Before my attempt was made, some trials were made by Mr De La Rue and others, but I am not able to say what is the value of their results'.[16] The Committee responded by inviting more photographs 'from telescopes of the largest size which can be made available'.[17] The reader may see Phillips's colour Moon photo No. 2 reproduced in the in this journal (see Plate 4 on page 55). It is easy to imagine the impact of displaying it alongside his drawing of crater Gassendi.

Warren de la Rue's reflector was the finest available. Stimulated by seeing at the Great Exhibition in 1851 the daguerreotype photo of the Moon taken with the Harvard College Observatory's 15-inch refractor, De la Rue had in the autumn of 1852 begun experimenting with the wet collodion process available that year. With exposures of 10 to 30 seconds he obtained images large and clear enough to show surface features, and exhibited photographs in early 1853 to the RAS. He then succeeded in securing a strong image of the Moon by an exposure of 4 seconds.[18]

Nevertheless, the technology limited the results. John W. Draper (1811–82) of New York in 1840 had used a 5-inch reflector to secure a daguerreotype photograph of the Moon in 20 minutes, and in 1843 obtained improved results. In 1850 at Harvard the director William Cranch Bond (1789–1859) and his assistant John A. Whipple (1822–91) took daguerreotype photographs of the Moon with exposures of 20 minutes on the 15-inch refractor. Phillips in 1853 went on to ascertain precisely that for his 11-feet focal length refractor the active (chemical or actinic) focus was ¾-inch beyond the visual focus, he improved the sensitivity of the collodion, improved the adjustment of the Huyghenian eyepiece, and thereby achieved photographs of 2-inch diameter with 20-second exposures. However, because in a refractor the chemical and visual foci are not coincident it was very difficult to achieve a focus on collodion film plate, so that little more than major outline was clear. His long focal length refractor was unsuitable for advances in photography. Nevertheless, his improvements in cutting his exposure time by a factor of 15 and imaging an area four times larger amounted to a sixty fold improvement. He continued his experiments until he left for Oxford in October 1853, by which time he concluded:

> I would advise not to continue this [photographic] kind of work, but to go on with eye-draughts and the micrometrical measures, and as soon as any one mountain should be well sketched, to repeat copies by photography and get them criticized and completed by other observers. Thus a strong interest would be maintained in the subject, and it would be really making progress.[19]

De la Rue built a copy-apparatus to make enlargements up to 38 inches in diameter, but these also magnified every defect in the collodion emulsions. The scheme did not proceed further in the 1850s. Only Phillips and De la Rue had achieved success by 1853, and neither had a clock drive on their telescopes. James Nasmyth, Professor Piazzi Smyth in Edinburgh, and Professor James Challis in Cambridge all supported the drawing trial, but could not at that time commit to a programme.

Phillips arrives in Oxford

In 1853 Phillips was appointed Deputy Reader in Geology at Oxford; he became Reader in 1856 and Professor in 1860. He was Keeper of the Ashmolean Museum 1854–57, and then of the new University Museum as it was built.[20]

Arriving in Oxford in October 1853, Phillips had an exceptionally broad view of geology, he had innovated statistical and comparative approach to research, understood the mechanics of instruments, was a skilled artist in drawing fossils, and had cartographic skills. He had a national reputation and network, and through the BAAS and the Royal Society maintained provincial and London connections and influence.

When Phillips came to Oxford he lodged for five years during term time with Charles Daubeny FRS (1795–1867), the professor of chemistry and of botany, and a founder member of the BAAS who had enabled Phillips to bring the BAAS's annual meeting to Oxford in 1832. Daubeny was a remarkable polymath who only five years previously had published an enlarged second edition of his book *A Description of Active and Extinct Volcanoes* (1848), the first edition of which Darwin had taken with him on his voyage on the *Beagle* in 1831. Daubeny's pioneering study of the ancient and active volcanoes presented his chemical theory of volcanic action, which postulated that such action results from penetration of water to the free alkali and alkaline earth metals supposed to exist beneath the earth's crust, which by their oxidation generated volcanic heat. The late eighteenth-century debate between Revd James Hutton's 'Plutonian' theory, which included subterranean heat to create volcanoes, and Abraham Werner's rival 'Neptunian' theory that volcanoes vented burning coal seams, was unresolved. The arguments continued, while understanding rock strata was increasingly and commercially important to railway and canal builders. Mapping rock strata and explaining their origin was Phillips's speciality. Daubeny, who collected geological and mineral specimens, was an experimental scientist who also used chemistry to explain botanical processes. The two friends surely had many stimulating conversations. In the preface to his own book *Vesuvius* in 1869, Phillips wrote of his early debt to Daubeny's stimulus, and of how the theory of volcanoes and their influence on geology had engaged the savants of the century.

Throughout Phillips's life the age of the Earth remained a magnificent problem. Phillips's biographer Jack Morrell summarized that a chapter in Darwin's *Origin of the Species* in 1859 discussed the imperfection of the geological record, and the succession of fossils in strata, and postulated hundreds of millions of years for some processes. Phillips refuted Darwin's theory, and in 1860 calculated that sedimentary rocks were about 96 million years old. In June 1861 William Thomson (1824–1907, later Lord Kelvin) asked Phillips whether he and other geologists subscribed to Darwin's 'prodigious duration for geological epochs'. In 1862 Thompson published an estimate of the Sun's age as being between 100 and 500 million years, and in 1864 as president of the Geology Section of the BAAS Phillips recommended Thompson's and Samuel Haughton's calculations of the age of the Earth as lying between 98 million and respectively 2,300 million years. Phillips believed that the problems of geology 'needed the aid of the collateral sciences, of not just zoology, botany and chemistry, but also natural philosophy and astronomy'. He held that 'the study of the Earth's past overlapped with terrestrial and cosmic physics'. Phillips and Thompson both believed that the theory of the cooling of the Earth was essential to calculating its chronology, and sought to measure subterranean temperatures. By 1855 Phillips had arrived at a figure of 1°F per 45–60 feet of depth as the rise in temperature in the crust. In 1868 Thompson supervised a sustained effort to measure underground temperatures, and for it used the commercially available first-ever maximum thermometer designed and made in 1832 by John Phillips.[21]

Phillips's Observatory at Oxford, 1862

As regards astronomy, Oxford University had had no research observatory since 1839, when it had lost the use of the Radcliffe Observatory. The Professor of Astronomy, William Donkin (1814–1869), at his house in New College Lane taught students by their using sextants from the small windows of the little teaching observatory Edmond Halley had built.

From October 1853 Phillips spent terms in Oxford living with Daubeny but maintained his home in Yorkshire. In 1858 he was appointed Keeper of the new University Museum then under construction for completion in 1860. He moved into the Keeper's House beside the Museum in that year, and ordered a new 6-inch Cooke refractor with clock drive. Meanwhile De la Rue had in 1857 removed to Cranford and established his new observatory there, at last with a clock drive on the 13-inch reflector. His report in 1861 'The State of Celestial Photography' stimulated interest because he had in 1858 obtained stereoscopic photos revealing that linear rays from the lunar crater Tycho were ridges and furrows whose nature was not otherwise ascertainable.

In March 1862 Phillips sought to renew the lunar effort, stating that theories for the volcanic origin of lunar features could hardly be tested without 'a careful study of the magnificent volcanic surface of the Moon'. He said that the work of the past 10 years on 'mountains' and 'seas' by Nasmyth, on ring mountains by himself on Gassendi, and by Angelo Secchi on Copernicus, led him:

> To propose a plan of continuous work with one instrument to construct the fine detail only obtainable by drawing and the mind's interpretation on the basis of photographs, whose finest detail would then be improved upon.[22]
>
> He proposed as ideal the 6-inch achromat that he had ordered and which was now complete, to be placed in a transportable observatory. It should become the property of 'some scientific body' which would direct its work and ensure its long use. He offered his services for the first two years at Oxford. He proposed the purchase of the telescope for a maximum of 320 guineas, and of a movable observatory for £50, from funds of the Government Grant Committee through the Royal Society.

Edward Sabine, secretary of the Royal Society and chair of the Grant Committee wrote that he, William Sharpey (1802–80) and George Stokes (1819–1903) who were both current Secretaries of the Royal Society, and De la Rue unanimously supported 'your views on the importance of giving a new and well considered impulse to Selenography'.[23] But then the Committee granted only £100 towards the observatory, so that Phillips purchased the telescope himself.

Phillips established the observatory in July 1862, and his principal sequence of astronomical papers to various societies followed over the next three years as he set himself to grapple with what could be learned of the physical condition of the Moon, Mars and the Sun.

Overlapping Phillips's researches, William R. Birt (1804–81) presented to the BAAS in 1864 a modification of Phillips's proposal of 1862, taking up the cause of lunar mapping, and seeking to determine whether or not lunar features were of volcanic origin and the surface still active. With Phillips's encouragement the General Committee responded by setting up a sub-committee of which Birt was secretary 'for preparing

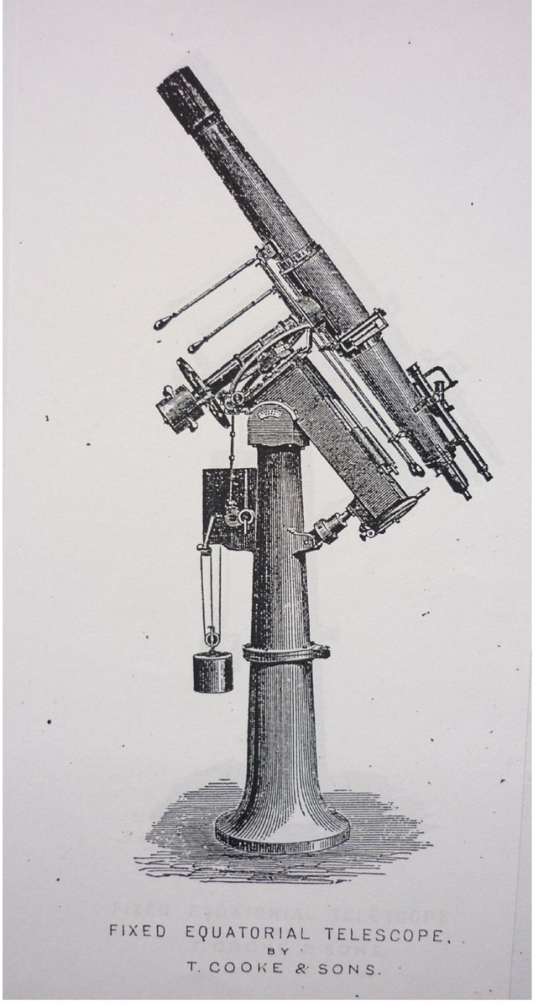

Fig. 3 A Cooke 6-inch Refractor c.1862. This drawing from Cooke's sales brochure of 1869, is presumably very similar to Phillips's 'accurate and convenient equatorial'. Photograph by the author, courtesy of the Borthwick Institute, York.

forms for registering the various craters and visible objects on the Moon's surface, and for constructing an outline map', which latter point was Birt's initiative, moving beyond Phillips's brief. Phillips cooperated, and Birt's Lunar Committee for Mapping the Surface of the Moon presented five reports between 1865 and 1869. It involved 11 regular members, of whom Rosse, John Herschel (1792–1871), Phillips, De la Rue, James Glaisher (1809–1903), Birt, and William Webb (1806–85) were involved throughout, and 24 other members contributed, including, for the last three years, Charles Pritchard (1808–93), who in 1870 was astonished to find himself the RAS's candidate for the chair of astronomy at Oxford. Birt, an able man but lacking independent means, was supported by

Fig. 4 The Oxford University Museum, 1862, and Phillips's Observatory. Phillips's observatory is the dark conical building in front of his Keeper's house. Photograph courtesy of Oxfordshire Studies, Westgate Library, Oxford.

Fig. 5 Phillips's Observatory of 1862. Close-up from the preceding figure.

John Lee (1783–1866) of Hartwell House, and was given free access to the famed Smythian 5.9-inch refractor there. By 1869, 2,099 features had been catalogued, and four areas near the centre of the visible hemisphere had been critically surveyed, mapped and published. The Committee believed that changes had been detected to craters Plato and Linné. Unfortunate with his patrons, Birt's scheme was too ambitious and only four portions of the proposed 200-inch map were completed, but he went on to establish the Selenographic Society in 1877 and was its first president.[24] In this way Phillips's initiatives in 1852–53 and 1862 stimulated a new era in selenography. This also drew in De la Rue by providing an application for his photographic experiments, so that in 1873 Phillips negotiated De la Rue's gift of his famed reflector to the University for Pritchard to deploy at its new observatory.[25]

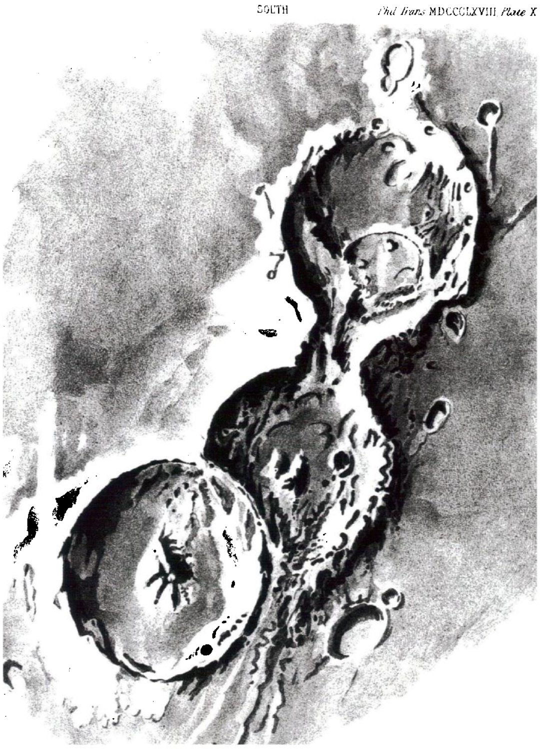

Fig. 6 Theophilus, Cyrillus, and Catharina, 1863. 'Theophilus intrudes into the older crater Cyrillus. Catharina includes the half-preserved ring of an older, smaller crater'.
John Phillips, 'Notices of some parts of the Surface of the Moon', *Phil. Trans. R.S.*, 158 (1868), 333-46.
By courtesy of Stella Brecknell, OUMNH.

In 1863 Phillips reported:

> 'Theophilus is 15 miles in length; the western crest is 15,000 feet high. In the 6-inch the floor appears clear, but beyond, to the north, east and south, all is curiously uneven in heapy little ridges and long partly fissured surfaces parallel to the ring. I can discern only one crater, but there are several smaller pits. I have searched long and frequently the central mountain to discover any cup on the summits of the 10 or more bosses that make up the rugged mass, elevation about 5,000 feet. None were found'.[26]

Since Phillips could find no 'cups' or craters on the '5-6,000 foot high central mass …very lofty and grandly fissured, long buttresses, many peaks and deep hollows', which he saw 'divided by deep chasms radiating from the centre, and resembling an uplifted mass which broke in radiating cracks in the act of elevation', he concluded that the origin was due to displacement of a solidified part of the Moon's crust, like the up heaved French volcanic region of Mont D'or.[27] We now know that Theophilus is an impact crater whose central peak is created by the 'slump-rebound' of material temporarily melted by the impact flowing outward, then rebounding and re-freezing, an explanation not available to Phillips.

Fig. 7 Theophilus with the 6-inch refractor at powers of 200 to 400 times.
By courtesy of Stella Brecknell, OUMNH.

Phillips and Mars

Mars is a small planet only twice the diameter of the Moon but always at least 140 times further away. It has an elliptical orbit that brings it relatively close to Earth every two years, but some of these oppositions or approaches are nearer than others. Then because the orbit of Mars is slightly inclined to that of the Earth, at some oppositions, Mars is high in the northern sky so easier to observe for northern observers, on other occasions it is perhaps nearer but too far south for good observation. Roughly speaking the cycle offers northern observers a close opposition high in the sky about once every 15 years. At the least favourable oppositions Mars may present a disc only 13.8 arc seconds in diameter, dauntingly small for visual observers, before retreating along its orbit to subtend less than 5 arc seconds. At its very best, about every 15 years, the disc may present a diameter of 24 or 25 arc seconds. Before the era of cameras, the observing window for Mars was short, and the relatively few observers with first-class instruments grasped the opportunities to glean what they could. Also because Mars has an axial tilt of 25.2° it has seasons, but they are out of phase with those of Earth, and either the south pole or the north pole may be presented at an opposition. Seen through the very variable atmosphere of the Earth, the features of Mars are always near the limit of visibility, so that different observers tended to interpret what they saw in different ways. Hence Phillips commented on the 'extremely diverse and at first perplexing appearances, which have been faithfully portrayed by Mädler, Herschel, De La Rue [sic], and others in their published drawings'.[28]

Phillips had long had an interest in Mars, and had observed it at every opposition since 1832. By happy coincidence the opposition on 9 October 1862 – only a few months after he had set up his Cooke – would present a disc of 22 arc seconds, the best since 1836, and the opposition of 30 November 1864 would offer a still considerable disc of 16 arc seconds but, crucially, more northerly so better seen.

Galileo had only been able to detect that Mars had gibbous phases. Hooke, Cassini and others saw spots and deduced rotation. Huygens and Herschel had seen polar caps. Taking advantage of the favourable opposition of 1836, Beer and Mädler in 1840 published the first complete map of the Martian surface. Limited by the 3¾-inch aperture of their excellent Fraunhofer refractor, they designated the dark areas by letters, and fixed the prime meridian in area 'a' (now Sinus Meridiani). The next significant chart resulted from the 1862 opposition. In particular, Frederik Kaiser at the new Leyden University Observatory observed the oppositions of 1862 and 1864 with his 7-inch Merz refractor, and from his observations published in 1864 the second map of Mars.[29]

Phillips for the 1862 and 1864 oppositions turned his new 6-inch Cooke to scrutinize the planet. In a paper to the BAAS in February 1863, and to Oxford's Ashmolean Society on 2 March, Phillips explained his new method of using the 1862 opportunity to determine whether there was permanence to the red areas supposed to be land, and the grey-green areas supposed to be seas:

> There were many sketches by many observers, but neither on comparing them one to another and to earlier published drawings by Herschel, Mädler and De la Rue, [W.S.] Jacobs and Secchi, could so much of correspondence be traced as to lead to a solid conviction that the features of the planet were constant.

He therefore considered the planet by arranging his own sketches:

> 14 taken between 14 September and 13 December [1862] in order of meridian line [Phillips's emphasis] on the face of Mars. Thus I obtained the data for constructing a globe of Mars, constructed one, and mounted it on a wooden frame. one, and mounted it on a wooden frame.

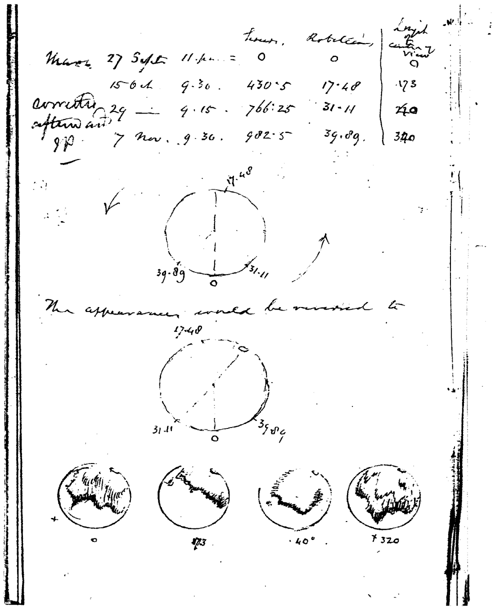

Fig. 8 Phillips's observing log, 27 Sept. to 7 Nov. 1863. Phillips transcribed four of his own drawings as he sought to relate their prominent features to those of his observations for which he had determined the meridians. Phillips's Observing Log, 1863, OUMNH Phillips Papers, Astronomy, Box 93/8, image, by the author, courtesy OUMNH.

> By considering the way in which this globe was presented to the observer on the Earth at different periods in the revolution of Mars, I was able to perceive very clearly the reason for the very different appearances presented by the drawings of the eminent observers named. It is supposed that this is the first example of a globe of Mars on which the main features were laid down… Many

drawings and three globes were exhibited.[30]

Beside the quality of his observations, Phillips's 'globes' were his important innovation. We should not imagine a sphere – he did not chart latitudes higher than 60°. He had devised a tool for arranging his own drawings so as to compare distinct features to copies of previously published drawings by other observers. For that purpose designation of a meridian of longitude was crucial so that they could be related to each other and to his own drawings. It is clear that at least the last of his globes, constructed in February 1863, was the basis for the first draft of his 360° chart.

Phillips had used four of his own best drawings to create a global map of those features he believed to be permanent because they are recorded by reliable observers.

By great good fortune as regards its survival, and good practice during routine cataloguing, Stella Brecknell, the Librarian at the Oxford University Museum of Natural History (OUMNH), discovered Phillips's original hand-painted draft map, and brought it to my attention. This important equatorial projection of 1864, the first British map of Mars, and in colour, the original 27.2 cm by 14.5cm, is published for the first time in this journal (Colour Plate 5 on page 58).

Phillips's note on the chart shows that he was satisfied as to some permanent features with 'edges', and the colours show that he shared the concept of land and seas. The map clearly shows his meridians of latitude and longitude. His focus had been to determine whether the supposed land masses had permanent edges. He did not attempt global charts to include the polar areas observed by others.

Having reported his observations principally to the Royal Society in January 1865, he set himself to write a comprehensive overview of all that was known of Mars, its physical characteristics, surface geography and atmosphere, for the new *Quarterly Journal of Science* which had a much wider circulation than the *Proceedings of the Royal Society*. That paper, 'The Planet Mars', was illustrated with his four best composite drawings of the two hemispheres of the planet (Fig. 9, right), and his equatorial chart to 60° north and south latitudes, revised from his colour chart after considering the best data from other observers (see Plate 5). He accepted the expanding and contracting polar caps as real, that they were snow, therefore that there must be water, and that there was an atmosphere to transport the snow. Since the snow spread on the ruddy part, it must be land. He concluded that observers are looking through an atmosphere partly clouded, yet enabling the true boundaries of land to be traced.[31]

In this way Phillips's new approach to Martian studies by constructing the first globe of Mars and relating features to a prime meridian and adding parallels of longitude and latitude had proved the consistency of the surface markings.[32] His conclusions in 1865 regarding a comparison of surface conditions to those on Earth added weight to research in advance of the very favourable opposition of Mars in September 1877. After that event the intense canal controversy (whether Mars exhibited linear features constructed by intelligent beings to carry water from the melting polar ice caps to areas closer to the Martian equator), and work with the new large refractors becoming available, overtook all previous work.

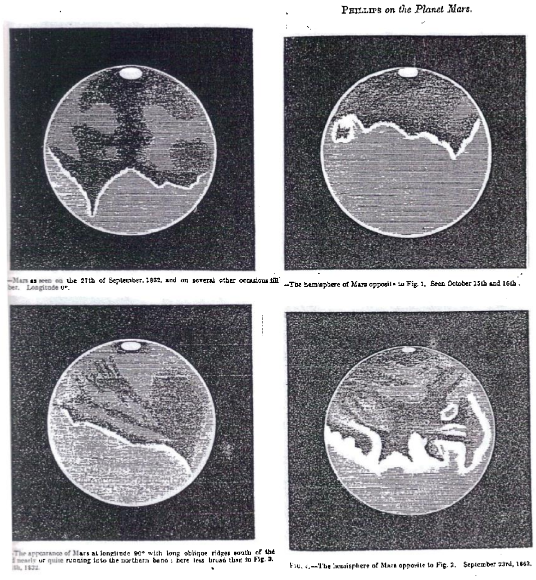

Fig. 9 Phillips's four best Mars drawings.
(1) Top left, is from several drawings made 27 Sept to 13 Dec. 1862. Longitude 0°. (2) Lower left, Mars at longitude 90°. Drawn by Phillips November 1832 in York. (3) Top right, the hemisphere opposite to (1), drawn 15 and 16 Oct. 1862. (4) Lower right, the hemisphere opposite to (2), drawn 23 Sept. 1862.
Photograph by the author from the re-production in Phillips's summary paper.
'The Planet Mars', *Quarterly Journal of Science*, II (July, 1865), 370-80, pp. 378-79.

Phillips's detailed observations of Mars in 1862 and 1864 were reported in the *Proceedings of the Royal Society* in 1865, and his paper 'The Planet Mars' was published in the same year.[33] His was thus the third map of Mars, the second Mercator projection – drawn in the same year as Kaiser's but published a

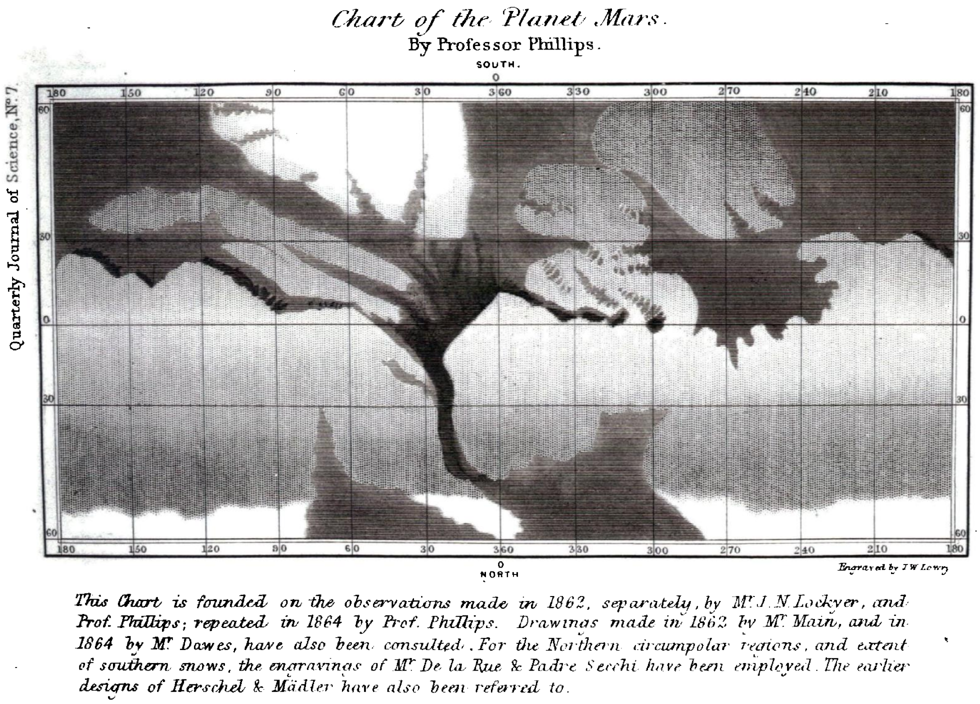

Fig. 10 Phillips's Chart of the Planet Mars, 1865.
The engraving made from Phillips's colour map of 1864 (Plate 5), for his overview paper in 'The Planet Mars', *Quarterly Journal of Science*, II (July, 1865), 370-80, facing p. 380.

year later – and the first British map of Mars.[34] Concerned only with the intriguing questions of physical geography and geology, and the challenge of the cartography, Phillips had not sought to propose a nomenclature. Phillips's prime meridian differs from that of Beer and Mädler, which by 1867 had been adopted by Richard Proctor (1837–88) and then Giovanni Schiaparelli (1835–1910).

Knowledge of Mars disseminated by Browning and Proctor

Astronomer and prolific science writer Richard Proctor recognized the opportunity to personally recalculate the rotation of Mars, to make known the new knowledge, to publish his own chart of Mars summarizing all the information then available including the polar caps, and to name features that observers could refer their observations to.[35] Principally constructed from 27 drawings by William Rutter Dawes that Proctor believed recorded finer details than had any other observers, and declaring that he had 'also consulted charts of Mars by Beer and Mädler and Professor Phillips', Proctor drew and in 1867 published a chart and applied his own nomenclature (now entirely superseded) of astronomers' names to all major features.[36] He achieved a relatively reliable depiction of the main outlines of the Martian geography.[37] John Browning (1835–1925) then used his instrument-making skills to construct a small spherical globe of perhaps 7.5 cm/3-inch in diameter, upon which he mounted his own beautifully rendered and coloured drawings adapted from Proctor's full polar projection chart. The globe was displayed to and admired by RAS members in 1868. Browning then photographed the globe in order to market stereoscopic views of Mars in 1869.[38] Proctor wrote the accompanying explanatory fifteen-page booklet, in which he credited Phillips with the 'first ever' globe of Mars, and added his own further revised chart of Mars.

Phillips did not publish on astronomy after 1868. He died in Oxford in April 1874 following a fall. During the previous two years he had used his influence to persuade the University first to build a new observatory for Charles Pritchard, who had been appointed Professor of Astronomy in 1870, and then to double the observatory to accommodate Warren De la Rue's gift of his 13-inch reflector. At the

Ashmolean Society's Memorial meeting in May, Professor Henry Smith (1826-83), Phillips's successor as Keeper, said: 'We have lost a man of science of the old type, a "Philosopher" of the olden school…of habitual and intelligent kindliness'.[39]

Plate 4.
Phillips: Moon Photograph No. 2 of 1853.
Taken 18 July 1853 with the 6¼-inch Cooke using 26 magnification, achieving a 1¼-inch image in 5 minutes. The second ever British photo of the Moon, the original enclosed to Edward Sabine, letter 20.7.1853, Royal Society, Sabine papers, MS 257, Sa 887.
Reproduced courtesy of the Royal Society.

Conclusion

We have barely glimpsed here the vigorous debates that raged throughout and beyond John Phillips's career: reconciling the Bible and the Flood to geology and then to evolution; the age of the Earth and the Sun; the nature of volcanoes and their contribution to chemical change in rock; trying to understand rock strata and composition. Jack Morrell, the historian of the BAAS and Phillips's biographer, asserted that Phillips was unique among the geologists of his time in believing that a cross-disciplinary approach was essential. Phillips tirelessly sought evidence that would assist understanding of the processes that might explain the surface of the Earth. To that end he designed and made instruments – thermometers and a telescope – in order to make physical measurements. Hence his experiment with photographing the Moon using the most powerful instrument he could borrow, and then, realizing the current limitations of photography, instigating the systematic investigation of the lunar surface on a cooperative and comparative basis. It was natural for him in 1862 and 1864 to painstakingly determine for himself what could be ascertained about the next accessible body, Mars. In each case he sought the highest quality data from other investigators. His achievements in astronomy included the second ever British lunar photograph, deliberately exhibited alongside his drawings to make a compelling case for continuing careful observing and drawing, by which he motivated a generation of British selenographers. He also devised the first Mars globe, and published the first British chart of Mars together with an authoritative overview paper that stimulated further research by others. By these researches Phillips contributed significantly to establishing the science of comparing the physical properties of three celestial bodies. This evolved to become designated, by Percival Lowell in 1905, the new science of planetology, specifically multi-disciplinary and comparative (see Note 1, below) – precisely the approaches that Phillips had advocated although Lowell was apparently unaware of his work – which is now the modern specialty of comparative planetology. Phillips is honoured by a crater named after him on the Moon, and one on Mars.

What would Phillips and his generation of diligent astronomers not have given to see the results of the Apollo Programme a century after their time, then the ongoing exploration of Mars, and the rover Opportunity's astonishing photographs of strata and erosion channels on the interior walls of Martian craters?

Acknowledgements:
It is a pleasure to acknowledge early encouragement and comment from Jack Morrell for my focus on Phillips's astronomy even as he worked towards his definitive biography. Similarly, Tony Simcock, Archivist of the Museum of the History of Science, Oxford, was constantly generous in sharing his expertise on Phillips and then scrutinizing my early draft. This paper could never have been developed without the especially generous help of Stella Brecknell, sometime Librarian at the Oxford University Museum of Natural History (OUMNH), who not only tolerated but encouraged my access to the very extensive Phillips Papers even while she was in the process of cataloguing them. She discovered a number of documents and drawings that I could hardly have hoped to find, especially Phillips's Mars Chart of 1864, and then she was immensely helpful in supplying photographs. I am also grateful to Bill Sheehan for comments on a draft version of this paper and the significance of Phillips map of 1864, and to Peter Gill who in refereeing this paper gave an exceptionally expert and helpful critique.

Notes and References

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Journal for the History of Astronomy, 24 (1993), 157-69. Lowell first coined and defined the term 'planetology' in a paper 'Means, methods and mistakes in the study of planetary evolution' submitted to the Royal Astronomical Society on 15 November 1905, but which was not published; in the next three years he wrote two books offering a bold approach to planetary evolution within the solar system, and Strauss page 3 adds in his Note 3 that Keith Baker, *The channels of Mars* (Austin, 1982) remarked that 'Lowell and his contemporaries were pioneers in the modern science of comparative planetology … the study of planets as a specialized field, one involving fascinating interdisciplinary work in geology, atmospheric science, geophysics, and even biology' (Baker, p.13). These authors seem unaware of Phillips's work, an omission that this paper seeks to rectify.

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4. Sheehan (1996), p. 34.
5. For more on the visual observations of Mars, see Davenhall, Clive, 'Mars before the Space Age', *SHA Bulletin*, 20 (Summer 2010), 29-40, especially 31-2.
6. Sheehan (1996), 46-48.
7. Anon, 'John Phillips', *Athenaeum*, 2427, (May 2, 1874), p. 598.
8. Anon, 'John Phillips', *Geological Magazine*, 73 (1870), 301-06; Anon, 'John Phillips', *Annual Report of the Yorkshire Philosophical Society for 1874* (1875), 14-19; Edmonds, J.M., 'John Phillips', *Dictionary of Scientific Biography*, 10 (1973) 583-4.
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10. *BAAS Report 1852* (1853), p. xxxv.
11. For a fuller account of the evolving international interest in mapping the Moon, see Sheehan, William P. and Dobbins, Thomas A., *Epic Moon: A history of lunar exploration in the age of the telescope* (Richmond, VA: Willman-Bell, 2001), Chapter 8.
12. *BAAS Report 1852* (1853), p. xxxv and Sabine's address, xliv-xlv.
13. *BAAS Report 1853* (1854), p. xxxiii, and 15-17.
14. *BAAS Report 1852* (1853), p. 31.
15. Photograph enclosed Phillips to Sabine, letter 20 July 1853, RS MS 257, Sa 997, Sabine Papers, Royal Society.
16. Phillips, John, 'On Photographs of the Moon', *BAAS Report 1853* (1854), 14-18, p. 15.
17. *BAAS Report 1853* (1854), p. xxxiii.
18. King, H.C., *The History of the Telescope* (London: Charles Griffin, 1955; reprinted New York: Dover, 2003), p. 224.; Le Conte, David, 'Warren De La Rue – Pioneer Astronomical Photographer', *The Antiquarian Astronomer*, 5 (February, 2011), 14-35, p. 17, citing *MNRAS*, 14, 1 (1853), p. 134.
19. Letter JP to Edward Sabine, 1 November 1856, Royal Society, RS MS 257, Sa 997, Sabine papers a1005, and BAAS Report 1854, p. 26.
20. Morrell, Jack, 'Phillips, John', *Oxford Dictionary of National Biography*, 44 (2004), 120-22.
21. This paragraph is drawn entirely from Morrell, Jack, 'Genesis and geochronology: the case of John Phillips (1800-1874)', in Lewis, C.L.E., and Knell, S.J. (eds)., *The Age of the Earth: from 4004BC to 2002AD* (London: Geological Society, 2001), 85-90.
22. *BAAS Report 1862* (1863), 31-5.
23. Letter Sabine to JP, 1 March 1862, Oxford University Museum, Phillips Papers, 1862/2.
24. Hutchins, Roger, 'Birt, William Radcliff', *Oxford Dictionary of National Biography*, 5 (2004), 853-4.
25. Hutchins, Roger, *British University Observatories 1772-1939* (Aldershot: Ashgate, 2008), 42-49.
26. Phillips, John, 'Researches on the Moon', *BAAS Report 1863* (1864), 9-10. He presented two drawings of crater Theophilus. For the description: Phillips, John, 'Notices of some parts of the Surface of the Moon', *Phil. Trans. R.S.*, 158 (1868), 333-46.
27. Phillips, *BAAS Report* 1863, p. 10.
28. Phillips, John, 'The Planet Mars', *Quarterly Journal of Science*, II, (July 1865), 370-80, p. 372.
29. Kaiser, Frederik, *Annalen der Sternwarte in Leiden*, 3 (1864).
30. 'Report of meeting 2 March 1863', *Proceedings of the Ashmolean Society, Oxford*, Bodleian Library, Ashmolean Natural History Society Dep C662, J. Phillips: ptd adds/25.
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32. Blunck, Jürgen, *Mars and its Satellites* (New York: Exposition Press, 1982), p. 188 onwards 'exclusively lists' maps and globes of Mars sh-owing new nomenclatures. Hence he excludes Mädler, Kaiser and Phillips from the maps, and he did not know of Phillips's 'globe'.
33. Phillips, John, 'The Planet Mars', *Quarterly Journal of Science*, II (1865), 370-380.
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37. For the full account of Proctor's and Browning's initiatives, and illustrations of Proctor's chart and Brownings remarkable stereograms, see Hutchins, Roger, 'Postcards from a Lost Planet II: Globes and Stereographs from the 1860s', *SHA Bulletin*, 21 (Autumn 2011), 27-32. Proctor published his account of Mars and a chart in *Half-hours with the telescope: a popular guide to the use of the telescope as a means of amusement and instruction* (1868) which went through several editions.
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39. Smith, H.J.S., Savilian Professor of Geometry, in Rolleston, G., 'Memoriam', *Proceedings of the Ashmolean Society* (18 May, 1874), pp. 2-11.

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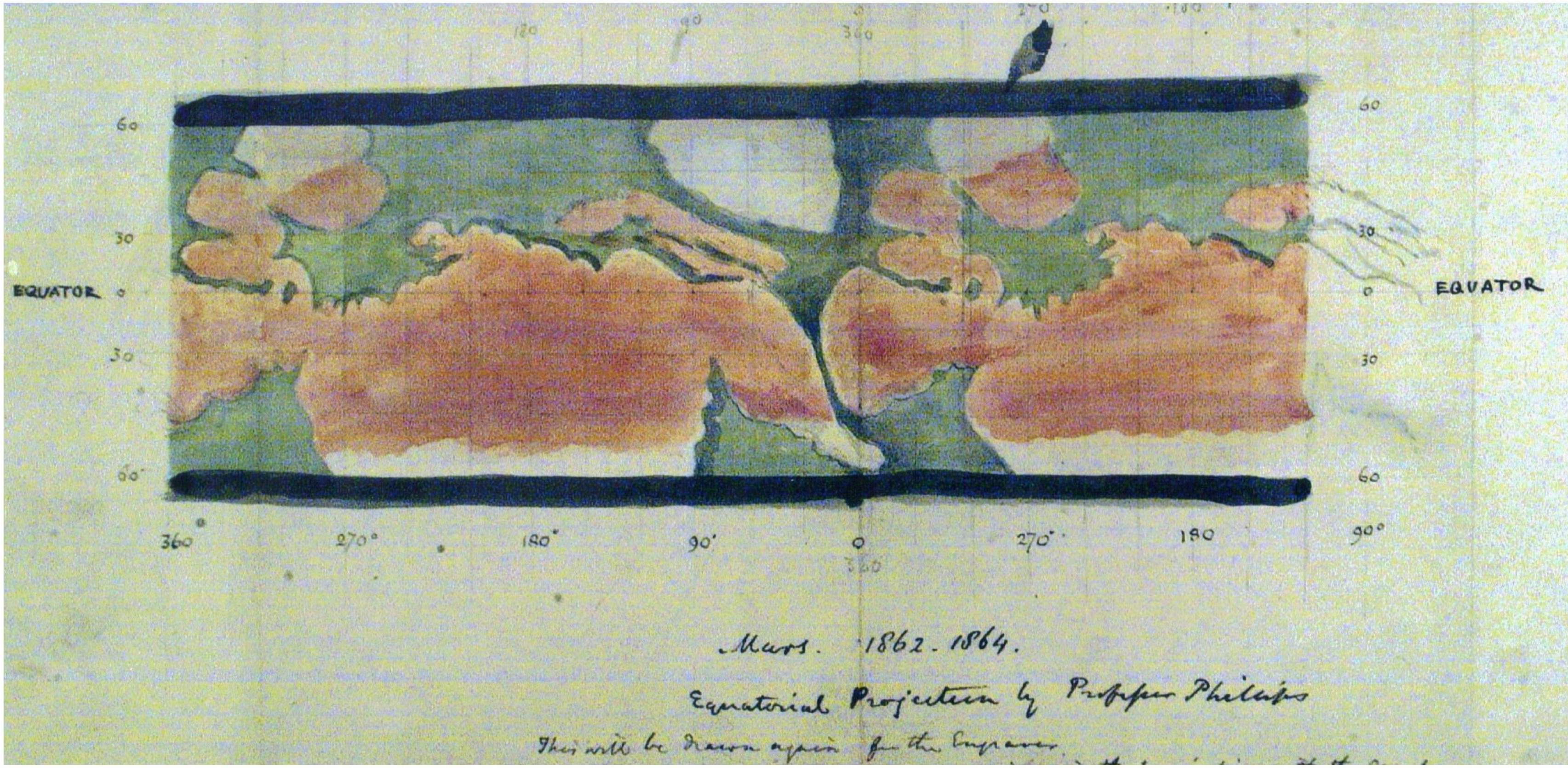

Plate 5. Phillips's original colour draft Mercator map of Mars (1864).
'Equatorial Projection by Professor Phillips', drawn and painted by Phillips in 1864. With Kaiser's map of 1864, one of the first two Mercator maps of Mars, the first British one, and it bears more convincing detail than Kaiser's. Some of the nuance of this coloured original is lost in the engraving made from it (Fig. 12). In a private communication Bill Sheehan pointed out that the colours are also fascinating, since the proper colouring of Mars has always been a vexed question. Original in OUMNH Phillips Papers, Out-of-sequence Box 1, 1864; photo very kindly supplied by Stella Brecknell, sometime OUMNH Librarian, and reproduced here for the first time, and at full size.
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