William W. Watts, pioneer Midlands geologist

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Abstract: W. W. Watts lived from 1860 to 1947, during which time he was a leader in geological thinking and played many roles in the early development of the geological sciences. He is best known for his geological mapping and interpretation of the ancient rocks of Charnwood Forest. This biography is presented as a review of his life as a geologist closely associated with Charnwood Forest, as featured in his book *Geology of the Ancient Rocks of Charnwood Forest, Leicestershire*, which was posthumously published in late 1947.

William Whitehead Watts was born at Broseley, Shropshire, on 7th June 1860; thus 2010 is the 150th anniversary of his birth. He died on 30th July 1947.

Watts' father was a music master and his mother (née Whitehead) was a farmer's daughter. Watts' education started at Bitterley School, near Ludlow, from 1869-1870 and was continued at Shifnal Grammar School 1871-3, before he went to Denstone College, near Uttoxeter, Staffordshire; this had only just opened as one of the Woodard Schools, with a leaning towards science and mathematics. As a bright scholar, he gained an Exhibition worth £40 to Sidney Sussex College, Cambridge, where he studied Chemistry under J.F.Walker, who persuaded him to take up geology as part of the Science Tripos. Watts soon made geology his main subject and in due course he gained a First Class Honours degree. While at Cambridge, Watts was active in the formation of the students' society known as the Sedgwick Club.

After graduation Watts gained valuable experience as an Extension Course Lecturer for the many adult education classes put on by Cambridge University throughout the Midlands. He taught courses in geology, physical geography and archaeology in no less than 36 towns from 1881 onwards, i.e. from the age of 21. Somehow he fitted in the post of part-time science master at Denstone College, Uttoxeter. He also took on the duties of deputy professor at Yorkshire College, Leeds, (later the University of Leeds) and taught at Mason College, Birmingham (later the University of Birmingham), covering for Professor Lapworth during his illness. He taught one-term courses at both Oxford and Cambridge Universities and gave two highly popular courses in Leicester. During this busy period he continued mapping the geology of his native Shropshire, where he had already found the graptolite *Dictyonema* (now *Rhabdopleura*) *flabelliforme*, so confirming the presence of late Cambrian strata (Tremadocian, now regarded as early Ordovician).

From 1891 onwards, Watts became involved with several leading geological institutions. Firstly, he was petrographer to the Geological Survey when they were mapping in Ireland; later he had the equivalent post at the Geological Survey's London headquarters. He then returned to academic life as assistant to Professor Charles Lapworth at Birmingham University from 1897 to 1906. Lapworth was Professor of Geology and Physiography (broadly equivalent to geomorphology today). Lapworth and Watts jointly contributed much to knowledge of the geology of the Midlands, particularly Shropshire. In 1906 Watts succeeded J.W.Judd as Professor in the Royal College of Science and Royal School of Mines (later Imperial College, part of the University of London), where he remained until his retirement in 1931, being instrumental in developing the College's courses in mining, petroleum and engineering geology, with specialist assistants in each of those fields. During World War I, Watts was an adviser to several Government Departments, ranging from Munitions and Aeronautics to Water Supplies. He reported on the future of coal-mining, and recognized that concealed reserves lay beneath the Trias between the known coalfields of the Midlands. He noted the possibility of the exhaustion of coal reserves sometime in the future.

At various stages Watts served on the Councils of the Geological Society, Geologists' Association, Mineralogical Society, Royal Geographical Society and the British Association. He was elected President of the Geological Society of London (1912), and later was

W.W.Watts (Photo: BGS archives).

Lapworth (left) and Watts (right) on the Corndon intrusion, Shropshire (Photo: Lapworth Museum, University of Birmingham).

Below: Rothenstein's 1931 portrait of Watts that hangs in Imperial College, London (Photo: Imperial College).

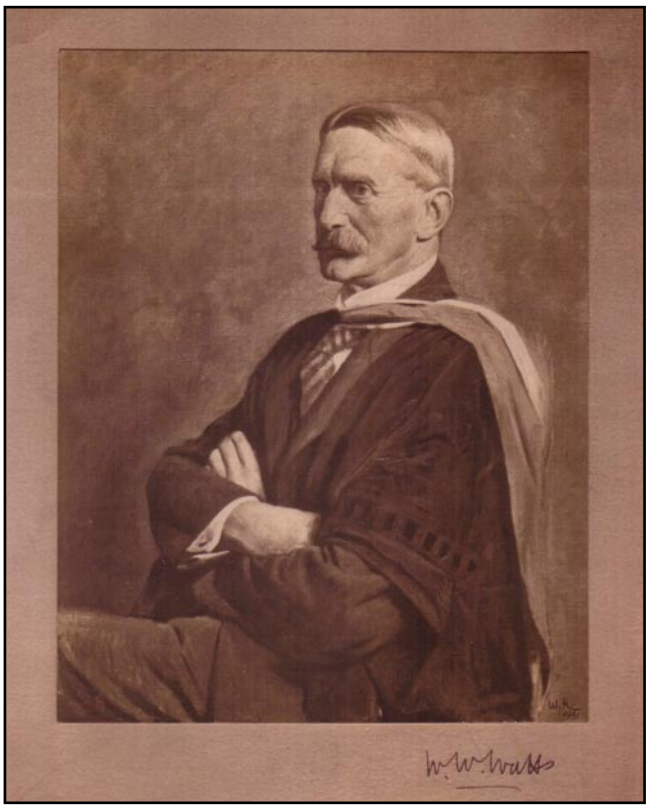
elected a Fellow of the Royal Society. He was awarded the Wollaston Medal by the Geological Society and was twice President of the Geologists' Association (1908-1910 and 1930-32), the Mineralogical Society and Section C (Geology) of the British Association (1903 and 1924). He was particularly keen on promoting the field excursions of the Geologists Association as an essential part of the enjoyment of geology (Sweeting, 1958). Watts received Honorary Degrees and other accolades from several universities. A complimentary dinner was held in his honour by the Geologists Association in 1937. On his retirement the Watts Medal was established for the best graduate student at Imperial College each year, and a portrait of Watts (c.1931) by Sir William Rothenstein still hangs in the College.

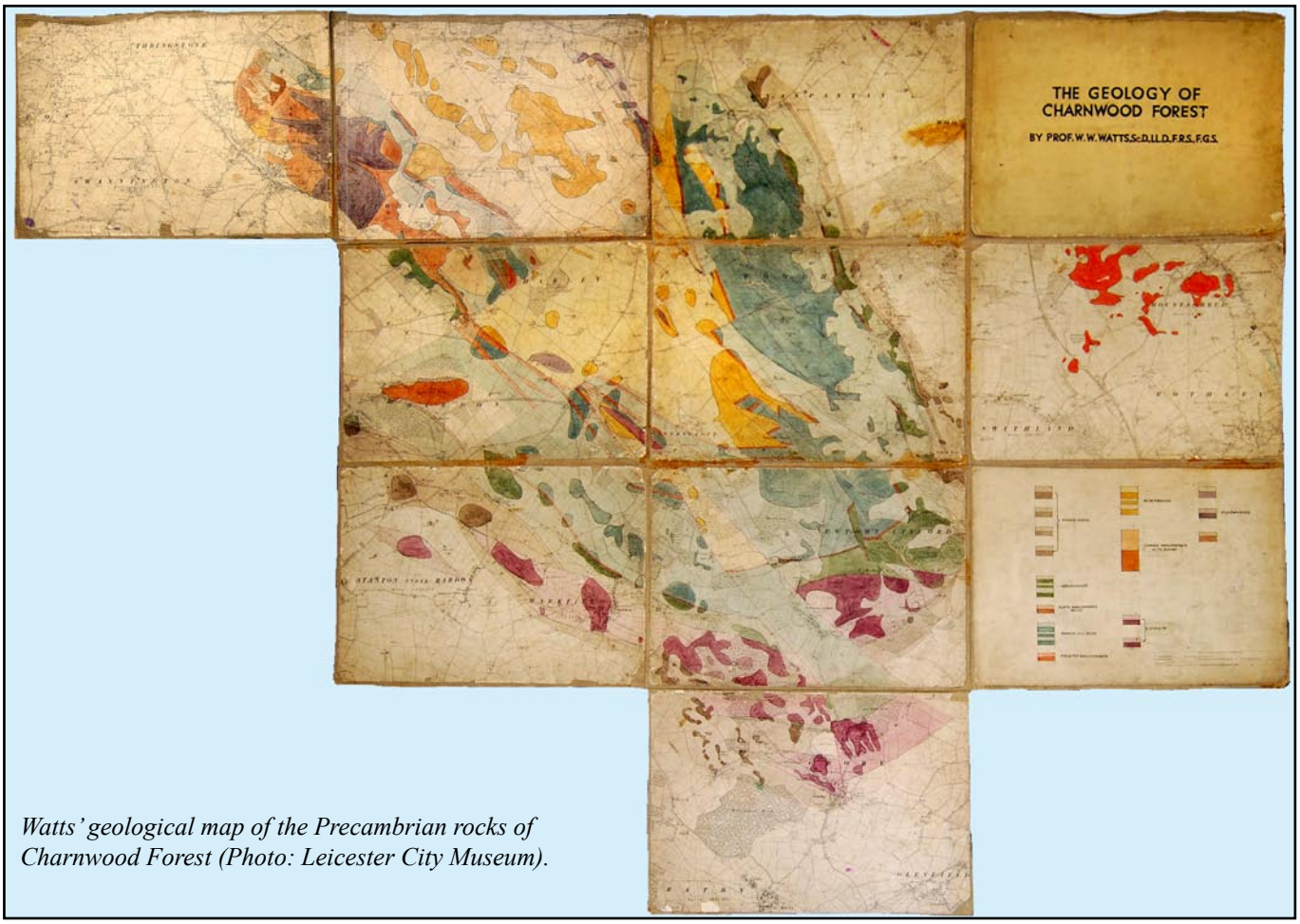
Watts was married twice, first to Louisa Adelaide Aitchison in 1889 but she died in childbirth only two years later. The daughter, Beatrice Mary Adelaide Watts, later married Professor W.G.Fearnsides, who established the Geology Department at Sheffield University (Fearnsides' daughter carried on the geological hierarchy by marrying Professor O.M.B.Bulman of Cambridge University). In 1894 Watts married Rachel Turnour, and their daughter Marjorie Lilian married and later moved to Australia. In his later years, Watts lived at Sutton, Surrey, and commuted to London daily.

Watts' Contribution to Geology

Watts' first original work was on the Breidden Hills near Welshpool, where he mapped the largely shaly succession and found *Trinucleus concentricus* in Caradocian strata and *Pentamerus oblongus* in the overlying Silurian, thereby demonstrating that there was a hiatus between the Ordovician and Silurian. He also studied the graptolites and was able to determine the distinctive faunas of the Wenlock and Lower Ludlow Series. While Watts was at Birmingham he learned much from Lapworth, who had solved the controversy of the relationship of Sedgwick's Upper Cambrian and Murchison's Lower Silurian by establishing the Ordovician system as it is known today. Though Lapworth did little research in Charnwood Forest, in 1898 he and Watts introduced the term Charnian for the ancient rocks there. Lapworth was also much involved in the recognition of the thrust structures in the Northwest Highlands of Scotland and this may have influenced Watts' early interpretation of the structure of Charnwood Forest as having overfolds and thrusts along its flanks.

In the late 1890s, as petrographer to the Geological Survey, Watts worked on the deformed Ordovician rocks of the Isle of Man when the island was being surveyed by G.W.Lamplugh (1897-1903). Watts supported Lamplugh's concept that the so-called "crush-conglomerates" were the effects of considerable tectonic deformation, though modern research has indicated that they are the results of submarine slumping on a large scale, with later cleavage superimposed.





Watts' geological map of the Precambrian rocks of Charnwood Forest (Photo: Leicester City Museum).

Charnwood Forest

Watts' best known contribution to geology was his mapping of Charnwood Forest which he began in 1896. The original of his 6 inches to 1 mile map is in Leicester Museum and copies are lodged in the British Geological Survey's archives and in the Geology Department of Leicester University. His work was incorporated into Fox-Strangways' maps and memoirs for the Leicester area (Fox-Strangways, 1900, 1903 and 1905). As early as 1896 Watts published an outline account of Charnwood Forest and drew attention to the weathered surfaces of the pre-Triassic rocks. Though Watts published further short accounts of the Charnian in 1907 and 1910, he did not complete his Charnwood book until long after retirement and it was published posthumously in 1947. In these publications he linked together the stratigraphy of the isolated outcrops to construct a map which depicted both the outcrops and inferred sub-Triassic subcrops. Together they make up the striking scenery of Charnwood Forest (see Ambrose *et al*., 2007). Watts found that there were no reliable fossils to help correlation, though his 1947 book recorded a few "worm burrows" which F.W.Bennett had found in Deer Barn Spinney in Bradgate Park. Watts failed to notice the abundant worm burrows in the Swithland Slate, best seen in tombstones in Leicestershire churchyards, and later identified as the trace fossil *Teichichnus* (Bland & Goldring, 1995; McIlroy *et al*., 1998) which has indicated that this slate, the highest unit of the Charnian succession, could now be regarded as of early Cambrian age.

In a review of the Leicester Literary & Philosophical Society's Geology Section activities, published posthumously in 1935, Dr F.W.Bennett paid particular tribute to Watts' inspiration: "his delightful descriptions clothed the story of Charnwood Forest with a garb of romance and made this small area a source of never-failing delight". Watts led numerous excursions into Charnwood Forest, particularly for that Society's Geology Section.

Watts was rather dismissive of the ring-shaped trace fossils in the North Quarry of Charnwood Golf Course, now known to be important components of the late Precambrian (Ediacaran) fossil assemblage (Boynton & Ford, 1995). Apparently he never saw the frond-shaped fossils though they were exposed in the same quarry.

Following encouragement from his colleague Lapworth, Watts established the succession of three series, namely the Blackbrook (hornstones and grits), Maplewell (agglomerates, tuffs, grits and hornstones) and Brand Series (conglomerates, grits, quartzites and slates). (Hornstones were very fine-grained siliceous rocks, occasionally used as hone-stones for sharpening tools). While Watts' stratigraphic sequence has stood the

The "Bomb Rocks" in Charnwood Forest (Photo: BGS).

test of time, it was revised and formalized by Moseley & Ford (1985 & 1989). Further revisions were made by the British Geological Survey (Worssam & Old, 1988; Carney *et al*., 2001, 2002, 2009; Ambrose *et al*., 2007; Carney & Ambrose, 2007). Correlation between the scattered outcrops is complicated by differences in the thickness and the relationships of units on either side of the Forest. On the west, the succession seemed to be less complete as it was interrupted by outcrops of igneous rocks, which Watts determined as lavas, "bomb-rocks", intrusive porphyroids (porphyritic micro-diorites) and "syenites" (actually diorites). However, there has long been some difference of opinion as to which rocks were extrusive lavas and which were intrusive sills (e.g. Bonney, 1915). The "Bomb Rocks" are now thought to be due to abrasive rounding in a volcanic vent, not to explosive eruption. The enigmatic andesite breccia of Bardon Hill is now regarded as having solidified in the shallow subsurface of a volcanic vent (Ambrose et al. 2007).

Regarding the structure of Charnwood Forest, Watts recognized that the Charnian sequence had been folded into an anticline oriented NW-SE and plunging southeast, and that slaty cleavage denoting compression with a similar orientation had been imposed. Later studies revealed that the orientation of the cleavage is variable and not quite parallel to the fold axis. The poor development of this cleavage in the nearby Cambrian rocks of Nuneaton led him to regard the compression as of pre-Cambrian age, though more recent research has argued that the cleavage is Caledonian (i.e. late Silurian) and that the adjacent Cambrian rocks were too shallow to be affected to the same extent.

Watts introduced the term "ripple cleavage" to define the refraction effect as cleavage passed through beds of different grain size a few centimetres thick. In his 1947 book Watts paid tribute to the pioneer work of Hill & Bonney (1877-1880) who had recognized the volcanic origin of what they called "the pre-Carboniferous Rocks of Charnwood Forest" by their petrographic studies; however, they did not deduce a stratigraphic sequence nor did they describe the anticlinal structure. Watts' papers included a diagrammatic section across Charnwood Forest with overfolds on each flank directed towards the centre and carried on low angle reverse faults (thrusts) dipping outwards, though this interpretation is not easy to deduce from his field map. Watts showed these alleged structures in a diagrammatic section in his 1907 review and it was repeated in his 1947 book (p. 96). However, the overfolds are shown by dotted extrapolations above the ground profile, and the thrust faults are not clearly identified on his map. The repetition of outcrops can be explained by normal faulting. The nature of recumbent folds above thrusts was not well understood at the beginning of the 20th century and he may have been influenced by Lapworth's recognition of thrust masses in NW Scotland: however Watts' misconception was an advance in structural geology. He realized that Charnwood Forest is a plunging anticline but apparently continued to believe in his idea of overfolds and thrusts until his death as the diagram was repeated in 1947. Subsequent re-mapping has discarded the concept. The Charnian strata were re-mapped in the 1920s with a few differences from Watts' map (Bennett *et al*., 1928). Charnwood Forest has been mapped again by John Moseley (Moseley & Ford, 1985, 1989), by Carney *et al*. (2001; 2002), by Ambrose *et al*. (2007) by Carney & Ambrose (2007) and by Carney *et al*. (2009). With modifications to fit modern rules of stratigraphic nomenclature Watts' stratigraphic divisions have generally been adopted by later authors.

The Mount Sorrel granite mass is close to the eastern margin of Charnwood Forest and has pre-Triassic erosion features similar to those of Charnwood Forest,

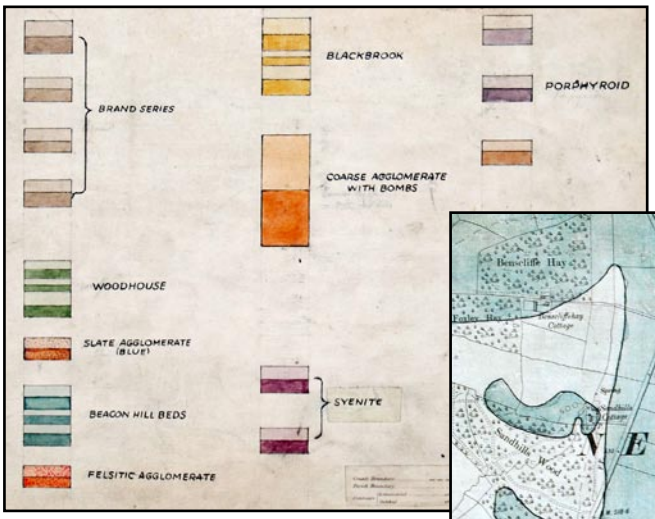
Beacon Hill tuffs exposed high on Charnwood Forest, with Loughborough in the distance (Photo: BGS).

but Watts recognized that it was a separate intrusion and that it was much younger, Watts noted the basic varieties of granite on its western flank. Later described by Lowe (1926), the intrusion is now regarded as of late Ordovician age (Carney *et al*., 2007, 2009). Watts noted that thermally metamorphosed slates along the western shore of Swithland Reservoir were relics of a former sedimentary cover of possible Cambrian age.

Watts and Lapworth introduced the term Charnian System as early as 1898; however the Charnian is now regarded as a local representative of the Ediacaran Period (Knoll *et al*., 2004), within the Neoproterozoic III, the youngest subdivision of Precambrian time. Neither Watts nor subsequent investigators have found any evidence of a pre-Charnian basement. In his 1947 book, Watts discussed possible correlations with various rocks in Wales and the Borders, in particular the Longmynd. However, although absolute dating of rocks by isotopic ratios was available by the 1930s, this method was not applied to the Charnian rocks until long after Watts' death and he made no comment on their absolute age in his book. Several isotope dates for the intrusive rocks, some of uncertain validity, were summarized by Boynton & Ford (1995); later, a series of dates for the volcaniclastic sediments ranging from 559-566 million years was reported by Compston *et al*. (2002) and further dates were discussed by Carney *et al*. (2009).

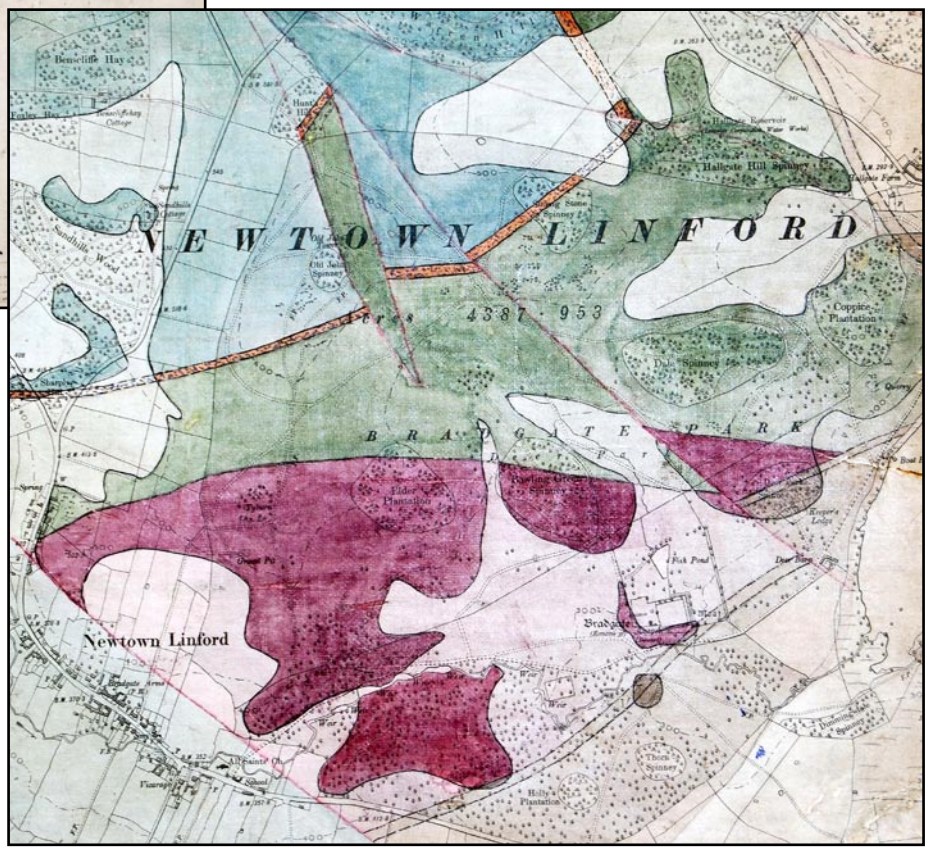
Though Watts did not discuss the probable extension of the Charnian beneath the younger Triassic and Jurassic of the East Midlands, it is likely that he was well aware of the possibility of a buried mountain chain (Pharaoh et al. 1987).

Watts had recognized that the landscape of Charnwood Forest was a group of hills in an ancient Triassic landscape by 1896, and this theme was expanded in detail by Bosworth in 1912 and by Raw in 1934. Watts argued that the landscape had been deeply eroded by Old Red Sandstone times, forming an island or archipelago on the margin of the later Carboniferous basin of the South Pennines, finally buried by Triassic deposits, from which the Charnian rocks were now being exhumed. Watts commented that the area could be compared to the Arizona desert though no record that he ever visited Arizona has been found. Firstly, the rocks were compacted, cleaved, folded and faulted to form mountains. Secondly, there was intense erosion and thirdly came the arid conditions of the Triassic period, when a sequence of thick red mudstones (the Keuper Marl, now known as Mercia Mudstones) lapped up against and finally covered the eroded mountains. The rounded forms of some of the "tors" of ancient rocks buried by Triassic sediments were attributed to desert weathering with sand-blasting. Watts realized that there had once been a cover of marine strata in Jurassic and Cretaceous times, as their escarpments

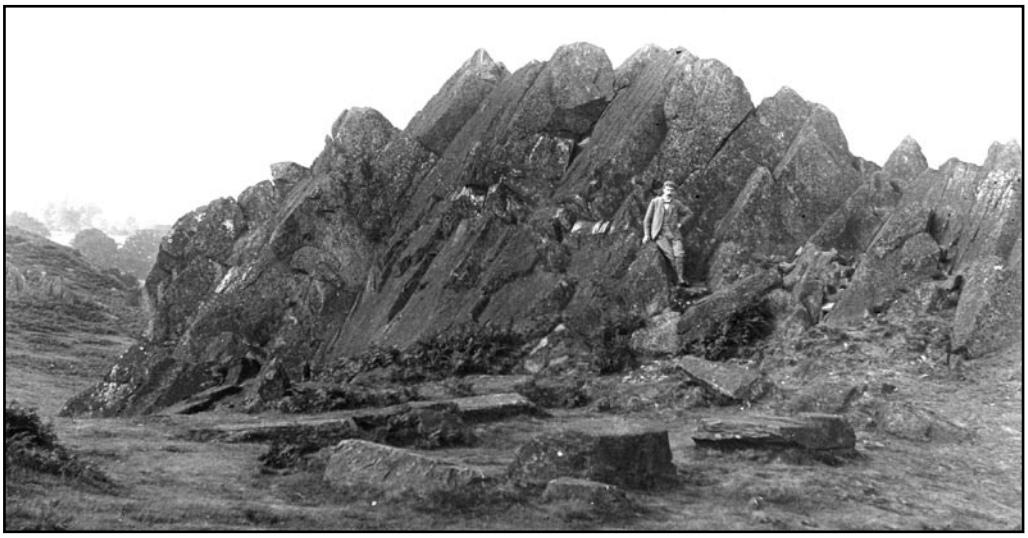


The key to Watts' map of Charnwood Forest.

(Photos: Leicester City Museum)



Detail of the Bradgate Park area on Watts' geological map of Charnwood Forest.



Watts on the Hanging Rocks, which are now within Charnwood Golf Course (Photo: BGS archives).

had only retreated a few kilometres to the east but little could be deduced of the nature of the former cover. The final stage in the evolution of Charnwood Forest scenery was the progressive removal of the Triassic deposits during late Cenozoic and Pleistocene times, the latter being enhanced by glacial scouring in the Ice Age. Watts also noted the radial drainage pattern of the streams in Charnwood Forest, which he regarded as flowing off a domed cover of Trias and gradually being superimposed on to the old rocks, creating the gorge-like features where the streams had been incised into the Charnian rocks. An alternative concept is that the superimposition was from the later Quaternary cover (Bridger, 1978).

Beyond Charnwood Forest

Between his busy life of lectures Watts led many field excursions – in 1909 he took Geologists' Association parties to Paris, Tenby, Frome, Stroud and North Wales. He published around 80 geological papers and his obituarist P.G.H.Boswell provided a list of 77 of these.

Watts conducted many field excursions in Charnwood Forest, the last in 1936, when he was aged 76. He occasionally showed foreign visitors round: one such was Johannes Walther (1860-1937), a German professor well known for his research on both modern and fossil desert weathering processes. Walther pointed out to Watts that the basal Triassic sediments formed infills to buried channels visible as sections cut in several quarries in the Charnian rocks and that these could be compared to the "wadis" of North Africa. Watts took up his idea and was subsequently nicknamed "Wady Watts".

Several contemporary Leicestershire geologists doubtless influenced Watts' geological thinking on Charnwood Forest: these included W.J. Harrison, J.D. Paul, C. Fox-Strangways, M. Browne, F.W. Bennett, E.E. Lowe, F. Jones, H.H. Gregory, and A.K. Coomaraswamy (see Appendix).

Watts enthusiastically took up the use of a motor car to get him to his many engagements and for field work, and he was an early member of the RAC. However, he disliked other modern inventions such as the telephone and refused to have a secretary, typing his own correspondence and reports on an ancient typewriter.

The long obituary of 16 pages prepared by P.G.H.Boswell, one of his colleagues on the Geological Survey and later Professor of Geology at the University of Liverpool, described Watts as an eloquent lecturer and pioneer in geological teaching methods, and as one who took great interest in his students, being proud of the many who made their way into senior positions as Professors or as Directors of Geological Surveys. Watts was staunchly conservative in his political views, and had strong likes and dislikes. His favourite author was Kipling, and he liked parodies and nonsense verse, both sometimes adapted for geological audiences. He was a heavy pipe-smoker throughout his life. He was active to a ripe old age and gave an address at the age of 85 to the Geological Society's first William Smith meeting in 1945 on "The Geological Society; its work and workers", though his research on Charnwood Forest had only a brief mention therein.

Though Watts set the scene for subsequent research in Charnwood Forest, he would have been amazed at the progress made since he died in 1947, especially in the palaeontology of the Ediacaran fossils found there, the assignment of the Swithland Slate to the Lower Cambrian on the basis of the trace fossil *Teichichnus*, in the isotope dating of the rocks and in the discovery of plate tectonics with its relationship of the Charnian to the former continent of Gondwanaland.

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Watts' Associates and Collaborators

This list is of geologists who were contemporaries of Watts and with whom he discussed many aspects of his research.

William Jerome **Harrison** (1845-1908) came to Leicester as Chief Curator of Leicester Museum in 1872 before moving to Birmingham in 1880. He was very active in local geology and was also a keen photographer, so he illustrated his book on the Geology of Leicestershire and Rutland, published in 1877, with his own photographs; many of the photographs in the Lapworth archive in Birmingham are thought to be by Jerome Harrison. He was a leading member of several photographic societies and published books and articles on photography. He was especially interested in Pleistocene geology, and recorded exposures no longer available. In 1953 Professor F.W.Shotton named the glacial lake that had covered much of the Midlands Lake Harrison after him.

Charles **Lapworth** (1842-1920) was the first Professor of Geology and Physiography (broadly the same as geomorphology) at Mason College, later the University of Birmingham. He was a pioneer in unravelling the geology of Shropshire, the Southern Uplands and, later, the Northwest Highlands. He was Watts' mentor and collaborator in working out the geology of Shropshire, particularly the area around the Longmynd, and he steered Watts to Charnwood Forest, where he mistakenly tried to interpret some of the structures as overfolds and thrusts. Watts wrote extensive obituaries of Lapworth, whose son Herbert Lapworth was an engineering geologist based at Imperial College.

Thomas George **Bonney** (1833-1923) was professor at University College, London. He and Edwin Hill were both Fellows of St Johns College, Cambridge, and co-operated in petrographical studies of the pre-Carboniferous rocks of Charnwood Forest, so setting the scene for Watts' research.

Harry Edward **Armstrong**, F.R.S. (1848-1937) was a contemporary of Watts as a lecturer in chemistry at Imperial College. He recorded desert weathering on granite blocks at Mount Sorrel.

Thomas Owen **Bosworth** (died 1929) was a local geologist who followed Watts' lead in a study of the relationship of the basal Trias to the Charnian inliers. He later joined the Geological Survey in Scotland, and finally became an oil geologist working in various parts of the world.

Frank **Raw** (c.1875-1961) was a lecturer at Birmingham University in the 1930s, whose research included a re-interpretation of Watts' concept of pre-Triassic weathering of the Charnwood and Mountsorrel rocks.

Percy George Hamnall **Boswell** (1886-1960) was a colleague of Watts at Imperial College. He worked with the Geological Survey in East Anglia before moving to the Chair of Geology at Liverpool University, and wrote an extensive obituary of Watts for the Royal Society.

John D. **Paul** was Honorary Curator of Leicester Museum from 1882 to 1890 and an active member of the Geology Section of the Leicester Literary and Philosophical Society. While he took part in many excursions to Charnwood Forest, his main interest was in the superficial (glacial) deposits of the Soar Valley.

Edwin E. **Lowe** became Director of Leicester Museum in 1907, retiring in 1940. His research was mainly on the Mountsorrel granite intrusion, which gained him a Ph.D., and he was President of the Leicester Literary and Philosophical Society 1922-23.

Hubert Harold **Gregory** (1891-1950, M.A.Oxon.) was born at Foots Cray, Kent. After service with the RNVR in World War I, he served as Assistant Curator of Leicester Museum from 1923 until the late 1940s, with responsibilities for geology. Apart from leading many excursions in Charnwood Forest, he was the organizer of the Museum's Saturday Club for children. One of these children was David Attenborough who attributed his early interest in geology to Gregory and often helped with classifying fossils in the Museum stores. Sir David's father, Frederick L. Attenborough, was Principal of University College, Leicester, where Gregory was a part-time lecturer in Adult Education.

Montagu **Browne** (1839-1903) was Curator of Leicester Museum 1881-1903 and contributed numerous notes on local geology as well as a manual on taxidermy.

Charles E. **Fox-Strangeways** (1844-1910) was a colleague of Watts at the Geological Survey and a lecturer at the Royal School of Mines (Imperial College). He mapped much of the geology of Leicestershire, and incorporated Watts' work on Charnwood Forest into the Geological Survey Memoirs.

Frederick William **Bennett** (died 1930) was a leading Leicester physician with a hobby of geology, particularly that of Charnwood Forest. Bennett warmly thanked Watts for his inspiring guidance, as recorded in his posthumous history of the Geological Section of the Leicester Literary and Philosophical Society in their Anniversary volume of 1935. Together with Lowe, Gregory and Jones, Bennett mapped the Charnian rocks, and their map of 1928 shows some differences from Watts' map.

Francis **Jones** was a Leicester man who became a lecturer at Imperial College. He collaborated with Bennett, Lowe and Gregory in Charnwood Forest in the 1920s, with particular emphasis on the joint pattern in the igneous rocks and on the cleavage. In 1926 he published early accounts of the petrology and structure of Bardon Hill and of the joints and dykes of Groby.

Ananda Kentish **Coomaraswamy** (1877-1947) took many of Watts' photographs. He was a Tamil who studied at Imperial College and met Watts there. He later became Director of the Geological Survey of Ceylon (now Sri Lanka) and finally moved to America.

Left: Professor Charles Lapworth (photo: Lapworth Museum). Centre: Charles E. Fox-Strangways (photo: Leicester Lit. & Phil. Soc, and Leicester Museum). Right: Dr. F. W. Bennett (photo: British Geological Survey).

Watts' publications on Charnwood Forest

1895. Notes on some specimens collected in the Trench, Brazil Wood, Charnwood Forest. In J.D.Paul: "Cutting in the Swithland Reservoir". *Transactions of the Leicester Literary & Philosophical Society,* **4**, 12-13.
1896. Notes on the Ancient Rocks of Charnwood Forest. *Geological Magazine,* Decade IV, **3**, 485-487.
1896. Notes on the Ancient Rocks of Charnwood Forest. *Report of the British Association,* 795-797.
1896. (with G.E.Coke & J.W.Carr). Excursion to Nottingham and Leicester. *Proc. Geologists' Association,* **14**, 430-433.
1898. (with C. Lapworth).A Sketch of the Geology of the Birmingham District. *Proceedings of the Geologists' Association,* **15**, 313-428 (Charnwood pp. 323-335 & 417-418).
1898. (with G.J.Binns & C. Fox-Strangways) Notes on some rock specimens from borings at Netherseal. *Transactions of the Federated Institution of Mining Engineers,* **13**, 599-601.
1898-1909. Annual reports to the British Association on photographs of geological interest (the photographs are now archived at the British Geological Survey, Keyworth).
1899. Excursion to Charnwood Forest. *Transactions of the Leicester Literary & Philosophical Society,* **5**, 309.
1899. Notes on the surface of the Mount Sorrel Granite. *Report of the British Association,* 747 (also in *Geological Magazine*, Decade 4, **6**, 508).
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1947. *Geology of the Ancient Rocks of Charnwood Forest, Leicestershire.* Leicester Literary & Philosophical Society, 160 pp.

A bibliographic list of 77 Watts' publications on Charnwood, Shropshire etc is in Boswell's Obituary of Watts (1948). An archive of Watts' field notebooks is at Imperial College.

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