

SOME BRITISH IDEAS ABOUT ORE GENESIS FROM HOOKE TO WHITEHURST 1668 1786

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ABSTRACT

Riewerts' (1984) detailed study of early geological concepts is supplemented by evidence which shows that, although it is true that seventeenth and eighteenth century writers were considerably influenced by continental views of ore genesis, there were distinctly different views expressed by British natural philosophers, notably by Hooke between (1668 and 1690 (in Waller, 1705), Woodward (1695, 1728) and Leigh (1700). Unfortunately none elaborated their hypotheses and all had limited effect either on scientific thought or mining.

Robert Hooke's perceptive concepts of ore genesis have never previously been accorded the attention they deserve and it is asserted that in this, as with so many of his geological concepts, he was the most advanced thinker of his age. The influence of Hooke's discourses on Derbyshire writers such as Whitehurst (1778) appears to have been largely overlooked as have Whitehurst's own contributions to ideas about the origin of Derbyshire minerals by lateral secretion.

INTRODUCTION

In his fascinating paper relating early geological concepts to lead mining in Derbyshire, Riewerts (1984) stated that there were no early theories about the origin of Derbyshire mineralisation and implied that in the seventeenth and eighteenth centuries British thought on ore genesis was wholly dominated by Continental writers. Although it is true that early writers such as Webster (1671), Sherley (1672, Short (1734) and Hooson (1747) were greatly influenced by European writers, there were distinctly different views expressed by some British authors, notably Woodward (1695 and 1728), Leigh (1700) and Hooke in his discourses (published posthumously by Waller in 1705) and Whitehurst (1778). Unfortunately none of these men wrote detailed accounts of their hypotheses and their contributions have tended to be overlooked both by their contemporaries and subsequent reviewers. Leigh (1700) and Whitehurst (1778) developed their ideas from their observations in the Derbyshire orefield. Woodward was a Derbyshire man by birth and Hooke, although he had no known connection with the county, certainly posthumously influenced Whitehurst's thinking about many aspects of geology.

There was, therefore, a British input into early concepts of ore genesis and moreover a significant portion of this stemmed from studies of the Derbyshire orefield.

MID SEVENTEENTH TO EARLY EIGHTEENTH CENTURY

i) The intellectual setting

The second half of the seventeenth century was a period when attitudes about the earth and methods of investigation underwent a great transformation (Porter, 1977), emphasis being placed on the collection and collation of facts and the testing of hypotheses by experiment, and observation (cf. Boyle, 1666; Gunther, 1930). Folklore, Classical concepts and alchemy were being seriously

questioned but not necessarily disproved. For example Boyle (1680) in his brilliant essay 'The Sceptical Chemist', written in the form of a medieval disputation and first published in England in 1661, triumphantly debunked Aristotle's idea that natural substances, including minerals, were compounded of air, fire, earth and water but produced much evidence of minerals growing in situ at the present time - a view which influenced later Derbyshire writers such as Short (1734) and Whitehurst (1778).

In Britain the focal point of this intellectual revolution was the Royal Society, the luminaries of which were interested in the whole field of Natural Philosophy embracing both the Physical and Natural Sciences (including what we now call Geology). For instance, Robert Hooke, rightly characterised as the first English Geologist (Rossiter, 1935) was also the virtual founder of the science of meteorology, a physicist, a pioneer microscopist in botany, zoology and mineralogy, a prolific inventor of scientific instruments and a talented architect ('Espanasse 1956). Not surprisingly hardly any of his many and varied discourses to the Royal Society were published in his lifetime and in those that were printed after his death only passing reference is made to what were evidently very sophisticated opinions on the origin of ores and gangue minerals. This lack of published opinions on ore genesis should not be construed as evidence that Hooke's view were unknown to the scientific community until after his death, for they were presented verbally to the Royal Society on several occasions and doubtless frequently discussed.

In contrast to the essentially factual observational and experimental approach of most Fellows of the Royal Society, several authors attempted over-ambitious syntheses about the creation of the Earth. Fanciful and implausible as these treatises may seem today (e.g. Burnett, 1681; Woodward, 1695), they were genuine attempts to fit known facts into an all embracing theory constrained only by the necessity of it being consistent with the story of Creation as revealed by the book of Genesis. This latter constraint applied to all but the greatest of seventeenth century Natural Philosophers, such as Hooke. Nevertheless within this constraint considerable ingenuity led to a great diversity of models which broadly polarised around those who, like Burnett (1681), regarded the effects of Noah's Flood as wholly destructive and those who regarded it as benign and constructive (e.g. Woodward, 1695). As in Hooke's discourses (Waller, 1705) only passing reference is made to the origin of ores in these treatises.

The fact-finding approach, pioneered by the Royal Society, reached its peak with the publication of a series of privately sponsored Natural Histories of specific counties in the late seventeenth and early eighteenth centuries. These, the 'Survey Memoirs' of their day, embraced the whole field of Natural History including mining and industry and remain prime sources of information. Although some, such as Plot's volumes on Oxfordshire (1676) and Staffordshire (1686), are largely factual, speculations do occur notably in Leigh's 1700 account of the Peak District mineral veins. Attitudes and viewpoints of the authors of these 'memoirs' can thus be gauged by close reading of their texts which show that they, like most of their contemporaries, were constrained by the intellectual climate of opinion, being influenced particularly by the biblical account of creation, but able to take more independent views on the veracity or otherwise of medieval folk law, alchemy and the classical Greek concepts of the Natural World.

ii) The Original Hypothesis

Modifications of older ideas such as the concept of ores growing like vegetables persisted (cf Boyle, 1680; Sherley, 1672). For example, Webster (1671) discussed at length the Continental theories and claimed that he had obtained several pounds of Ghurr from which 'metalline earths' grew to perfection (see Rieuwerts, 1984 for a fuller discussion). Close reading of

seventeenth century texts, however, demonstrates that there were other distinctly British viewpoints which seem to owe little to Continental writers.

Three schools of thought appear to have predominated. Firstly, the vulgar opinion was that mineral veins were part of God's creation and it was impertinent to enquire into their formation. Secondly, it was postulated that they, in common with many other features, were the result of Noah's flood and, thirdly, that minerals had a subterranean origin. Superimposed on these views were the myths and legends so admirably discussed by Rieuwerts (1984).

Much time and energy was spent by men such as Boyle (1666) and Woodward (1685 and 1728) testing the validity of these folk tales, particularly the assertion that minerals grow like vegetables and can, given time, replenish an exhausted mineral mine. Boyle (1680) accepted this view but Leigh (1700) firmly rejected this proposition, attributing a Tuscany example to soft ore moving back into the mine, particle by particle, carried by what nowadays we would call formation or ground waters. Equally firmly, Leigh was convinced that Derbyshire mineral veins resulted from the Deluge. He was impressed by pods of ore and of remains of animals and vegetables which were sometimes found in fissures. He stated (with the words 'opening of' inserted by the present writer) that no one who 'considers (the opening of) the Fissures of the Rocks, and closing of those again when the Metal entirely disappears no strings leading to the subsequent body.....cannot conclude these to be anything else than the Ruins of an Universal Deluge' (Leigh, 1700, book 1 pp 89, 90). Interpolation and interpretation is necessary to deduce the mechanism that Leigh had in mind but we know from his discussion of the formation of Poole's Hole (book 1, p. 187) that he regarded the Deluge as the cause of fracturing of ante-diluvium (i.e. pre-existing rock masses). He also rejected Woodward's thesis (1695) that all strata were deposited during the Universal Deluge, arguing from scriptural evidence that the hills existed before the Flood. His hypothesis of vein formation, therefore, was that Noah's flood fractured pre-existing strata and ore minerals were washed into the resulting fissures.

A contrasting theory, though still constrained by a Mosaic straight-jacket, was imaginately conceived by Woodward (1695). He maintained that all ante-diluvial (i.e. pre-Flood) rocks and metals were dissolved by the flood waters. He regarded fossils as the remains of ante-diluvial plants and animals which were destroyed by the Flood but which had somehow escaped from being dissolved. His perceptive observation that most rocks were stratified and that different strata contained different assemblages of apparently extinct plants and animals led him to a bizarre conclusion, namely that minerals and the remains of plants and animals were precipitated from the liquefying flood waters according to their specific gravity. Thus gravity stratifications was postulated but not tested. No doubt had he been taxed with the fact that dense ore minerals occur in vertical fissures in less dense sub-horizontal strata, he would doubtless have been forced to conclude that ore minerals were precipitated at a late stage from the liquefying flood waters. He was apparently not so taxed and his writings on genesis of ores such as gold (Woodward, 1728, p. 44) are vague and confusing. Nevertheless it is clear that Woodward, like Leigh (1700), attributed ore deposits to the effects of the Deluge, though his model was totally different from Leigh's. Though both stemmed from interpretations of Genesis, Woodward's ideas arose from the concept of a benign God using the Flood to recreate the world for Man's benefit, whereas Leigh's ideas envisaged God using the Flood to punish Man for his sins, exemplified by phrases such as 'Universal Destruction', 'the whole Globe were broke asunder' and 'terrible Confusion' (see Davies, 1969 for fuller discussion of religious constraints on scientific thought).

Although constrained by their personal scriptural interpretations both are essentially Neptunish in their outlook. Leigh's (1700) concept of ore genesis from a universal Deluge is remarkably similar to the 'New Theory of the Origin of Veins' from a universal primitive ocean published almost a century later (Werner, 1791) though conceived somewhat earlier.

In contrast Hooke's genius allowed him to take a more pragmatic view and, although deeply religious, his thinking was not constrained by the necessity of harmonising his hypotheses with the book of Genesis (Oldroyd, 1972; Drake and Komer, 1981). Unfortunately his views on ore genesis are referred to only in passing in his published discourses (Waller, 1705) and a fuller account namely 'A History of the Forms and Properties of Minerals and Metals' (Waller, p. 320) was apparently either never published or has not survived. There are, however, sufficient brief references, 'by the Bye', in his 1668 Discourse on Earthquakes (in Waller, 1705 pp. 279-345) to appreciate the main lines of his radical thinking.

Firstly, he believed that ores formed deep in the earth's crust and were now exposed at the surface due to subsequent lift and erosion. For example (Waller 1705, p. 317) he imagined that the lightest parts of the earth

"Lye next the Surface, and so heavier in Lower Parts, which make me imagine the natural place of Minerals is very deep under the Surface of the Earth, and (possibly) to be found under every step of Ground, were search made under it to sufficient depth; and the reason we find it sometimes near the Surface of the Earth is not because it was there generated, but because it has been by some former Subterraneous Eruption (by which those Hills and Mountains have been made) thrown up towards the Surface of the Earth".

Secondly, Hooke associated ore minerals with volcanic activity, viz (Waller 1705, p. 305)

"and some such Power as these Subterraneous Fires, seems to me to have been the cause of the strange Positions and Intermixture of the Veins of Ores and Minerals in the Bowels of the Mountains, where, for the most part they are now found".

Furthermore he suggested that minerals were precipitated from Mineral Waters and

"all kinds of Talk and Spar, most Ores and Marchites, Alumen Plumeum and Asbestos; Fluores, Crystals, Cornish-Diamonds, Amethysts and divers other figured Mineral Bodies, may be generated from their Crystalization or coagulation, out of some Mineral Waters".

Moreover Hooke claimed that he could verify this experimentally and could

"add divers Experiments, by which several of these Concretes may be in a short time made artificially by several Chemical Operations".

Finally, Hooke believed that the fissures in which the ores occurred were formed by earthquakes (which he equated with volcanic activity) although, as the following passage (in Waller, 1705, p. 320) illustrates, he failed to distinguish between caves and tectonic fissures attributing both to earthquakes or volcanic eruptions, viz:-

"that whensoever an Earthquake raised up a great part of the Earth in one place, it suffers another to sink in another place; for Gravity is a principle that will not long suffer a space to remain unfill'd under to vast a pile of Earth as a Mountain, unless the Substances, so thrown up, be of very hard close and vast Stones that may, as it were, vault it: In which cases 'tis very probable (and Kircher and divers other Authors that

write of Mines and Quarries, give us many instances to confirm it) that these Cracks and Cliffs so left, are fill'd up with such Petrifying or Mineral Waters as do make great varieties of Stones, Marbles, Sparrs, Caulks, and Ores, and so there is made a transposition as well as a transformation. Which supposition (by the way) I think will furnish a very probable reason of the shape of the Veins and Cracks of speckled Marbles and other Stones, of the form also of the Veins of Ores, Stones Clays, etc. of the Earth, and of their so mixing together; of the lying of Mettals in Mountains and other Mines".

In summary, therefore, Hooke in 1668 (in Waller, 1705) argued that ore minerals were generated in depth in the earth's crust, associated with sub-surface volcanic activity and precipitated from mineralising waters in fissures which had been opened by earthquakes. Before hailing Robert Hooke as a pioneer of the magmatic-hydrothermal school of ore genesis it should be noted that in 1668 he did not discuss the source of the "Mineral Waters" and it is not clear if he envisaged these fluids being expelled from what nowadays we would call magma or whether the "subterranean fires" simply provided the heat to circulate pre-existing mineralising waters, nor did he discuss their composition. By 1690 (in Waller, 1705, p. 419) in a typical throw away paragraph, in a discourse on earthquakes (i.e. volcanic eruptions) of the Leeward Islands Hooke described the mineral waters as being "impregnated with Saline, Metalline, Sulphureous, or other substances", and associated them more closely with volcanic activity, here in a near surface setting, than hitherto, viz:-

"Remarkable in these Relations, is the Chapping and cleaving of the Earth and Rocks, and the spouting out of them of stinking Water to a great height; as also of Smoke or Dust, which serves to explain the Reason and Causes of the Flaws and Veins in Marbles and other Stones; for by the Power and Violence of the Subterraneous Heavings or Succussions the Stony Quarries become broken, flawed and cleft, and Subterraneous Mineral Waters impregnated with Saline, Metalline, Sulphureous, or other Substances are driven into them and fill them up, which having petrified Qualities in them, do, in process of time, petrify in those Clefts, and thereby form a sort of Stony Veins of different Colour, Hardness, and other Qualifications, than what the parts of the broken Quarry had before, and oft time inclose divers other Substances by their petrifying Quality, which have happened to fall into those Clefts, and thence sometime there are found shells petrified in the middle of the Vein, as I have seen, and other Substances. These Clifts or Chaps happening not only upon the Land, but even under the Sea; so that not only the Sea-water may descend and fill up those Clefts, but it may carry with it Sands, Shells, Mud, and divers other Substances from the bottom of the Sea, that then lay above it, there to be, in process of time, changed into Stone somewhat of the Nature of this which hath been so cleft".

Although it is easy to read too much into Hooke's words it is interesting that he described the mineralising water as saline and was contemplating a mixing with sea-water more than 270 years before the role of sea water in vein type mineralisation began to be seriously considered. This passage also demonstrates the flexibility of Hooke's thinking compared with Leigh (1700) ten years later. Whereas Leigh latched on to "Shells petrified in the middle of the Vein" (presumably riders of fossiliferous limestone) as incontrovertible evidence of Noah's flood being responsible for mineral veins, Hooke wrote of sea-water percolation and envisaged a dual origin for the veins and the shells within them.

Hooke has long been given credit by many authors for his advanced and basically correct concepts on the nature of fossils (e.g. Lyell, 1830; Woodward, 1911; Rossiter, 1935; Cox, 1956). His prophetic remarks about the

possibility of erecting a chronology using fossils has equally frequently been quoted though its significance may have been misinterpreted (cf. Edwards, 1936; Rossiter, 1937). More recently the breadth and essential correctness of Hooke's concept of denudation cycles has been emphasized (Davies, 1964, 1968; Westfall, 1969). His daring suggestions about the possibility of changes in the Earth's axis, its centre of gravity and remarks foreshadowing the theory of polar wandering and palaeoclimatology have all been discussed (Turner, 1974; Drake, 1981; Drake and Komar, 1983). Strangely, Hooke's views on minerals and mineralisation have been neglected. Drake and Komar (1981) acknowledged that Hooke, like Steno (1669), was aware of the constancy of interfacial angles and, moreover, in his *Micrographia* (Hooke, 1665) went further attributing this relationship to the internal structure. Apart from this I am unaware of any commentary, which even mentions, let alone, discusses, Hooke's ideas about ore genesis. Brief though the reference to mineralisation are in his posthumous works, they indicate that Hooke had thought deeply and perceptively about the subject and at least deserves honourable mention in any history of the development of ideas about ore genesis.

MID TO LATE EIGHTEENTH CENTURY

The ideas of Hooke (in Waller, 1705), Leigh (1700) and Woodward (1695, 1728) on ore genesis seem to have had little or no effect on eighteenth century thought. There appears to have been no subsequently published reference to them and mid eighteenth century British authors such as Short (1734) and Hooson (1747) were more impressed by the work of Boyle (1680) and Webster (1671). Adams (1938) has shown that during the mid to late eighteenth century other ideas about the formation of mineral veins began to emerge from European writers notably that of lateral secretion (DeJius, 1770; Gerhard, 1781 and Lasius, 1789) and the Neptunish concepts of Werner (1791, but conceived much earlier). In Britain the most influential contribution was by Hutton (1795) who believed that sulphide mineral veins, like granite and basalt, were formed from injected melts.

Hutton, however, was not the only British writer to formulate ideas about ore genesis. In spite of contrary assertions (cf. Rieuwerts, 1984), Whitehurst (1778) did propose a theory of ore genesis and moreover, this, like Farey (1811) 23 years later, favoured lateral secretion. Whitehurst's hypothesis has probably been overlooked because it is in the first part of his book, and like Hooke (in Waller, 1705), is referred to only in passing. Most scholars interested in Whitehurst's contribution to our understanding of Derbyshire geology (e.g. Ford, 1974) have, not unnaturally, concentrated on the detailed account of Derbyshire geology in part 2. Whitehurst slightly amended the passages on the formation of minerals in the second edition of his book (1786) and it is this fuller version which is quoted below; the words underlined being additional to, or modifications of, those in the 1778 first edition.

"8. The constant accumulation of mineral substances in the caverns and fissures of the lime-stone strata is no less evident than the stony concretions.

9. The stalactites which hang from their lofty roofs, as icicles from the eaves of houses, are continually increasing in number and magnitude; and the bottoms and sides of the caverns are daily incrusting with spar, and other mineral substances. Such operations of Nature may be conveniently observed in those celebrated caverns called Pool's Hole, near Buxton, and Peak Hole, at Castleton.

10. Many of these subterraneous caverns and fissures are also incrusting with alternate laminae of spar, lead ore, zinc ore, fluor, and other substances, and in these recesses they crystalize various forms, peculiar to the nature, or affinities of their component parts.

Were we allowed to reason upon the general cause of these wonderful appearances, we should be apt to conclude from the various circumstances accompanying them, that they arise from water filtrating slowly thro' the incumbent strata; and taking up in its passage a variety of mineral substances, and becoming thus saturated with metallic particles, gradually exsuding on the surface of the caverns and fissures, in a quiescent state, the aqueous particles evaporate, and leave the mineral substances to unite according to their affinities."

These paragraphs are thus substantially the same as in the first edition, perhaps the most significant addition being the words "fluor, and other substances". The substitution of "heterogeneous substances" and "mineral particles" in the 1786 version shows that Whitehurst was refining his ideas about what was actually extracted from the superincumbent strata. Both versions show that Whitehurst thought that both stalactites and mineral veins formed by the same process namely by leaching of limestone by percolating waters or more succinctly 'lateral secretion' by meteoric waters.

The reasons why such a variety of different deposits formed evidently troubled him for in 1786 he added to the sentence, "Hence a variety of mineral bodies are daily forming" (Whitehurst, 1778, p. 17) as follows:-

"Hence a variety of mineral substances are daily forming in select bodies, though in one general mass, one part thereof consisting of spar, another of fluor, lead ore, the ore of zinc, crystal, or whatever substances may happen to have been collected by the water, in its passage through the incumbent strata.

Such crystallization however depends in some measure on the quantity of water exsuded through the pores of the stone; for if the quantity exsuded exceeds the quantity evaporated, stalactites are produced in one instance, and tubes in another."

Probably these additional statements do not clarify Whitehurst's opinions as much as he intended but they do at least confirm that he did concern himself with theories of ore genesis and he, not Farey (1811), should be credited with introducing the concept of lateral secretion into Derbyshire geology.

Both Whitehurst (1778 and 1786) and Hutton (1795) were greatly influenced by the posthumous works of Robert Hooke (cf. Drake, 1981) but the imprint of Hooke cannot be as clearly discerned on Whitehurst (1778). Nevertheless, Whitehurst (1778 and 1786), when discussing earthquakes, frequently cited the posthumous works of Robert Hooke. Although he did not acknowledge Hooke when writing about mineralisation he used the same analogy, with icicles, and proffered essentially the same explanation as Hooke (in Waller, 1705 p. 293) for the formation of stalactites. In view of Whitehurst's familiarity with Hooke's text it seems unlikely that he had not read Hooke's description and discussion on stalactites, particularly since it mentions the Peak in Derbyshire (Hooke, in Waller, 1705 p. 293 and 295). If Whitehurst did derive his ideas about stalactites from Hooke, he either misunderstood or rejected Hooke's views about mineral deposits preferring both to be formed by the same process thus ignoring Hooke's clear distinction between the effects of (cold) "petrifying waters" and a "saline or sulphureous Mixture, with the concurrence of Heat from some subterraneous Fire or Earthquake" (Hooke, in Waller, 1705 p.293). In addition, as is shown by the phrase, "a variety of mineral bodies are daily forming", Whitehurst (1778 p. 17 and 1786 p. 32) apparently still favoured the medieval view, perpetrated by Boyle (1780) that minerals were currently and commonly growing in mines. Although Whitehurst may properly be credited with being the first British writer to favour the formation of

minerals veins by 'lateral secretion', he favoured meteoric waters as the mineralising fluid and his concepts lacked the breadth and perceptiveness of Robert Hooke.

CONCLUSIONS

Contrary to previous opinions this research has shown that there were views expressed by British natural philosophers, during the seventeenth and eighteenth centuries, about ore-genesis, which were distinctly different from their Continental contemporaries. Amongst these ideas, those of Hooke formulated before 1668 (cf. Waller, 1705) were by far the most perceptive and most nearly coincide with the thinking of the twentieth century magmatic-hydrothermal school of ore-genesis. Apparently none of the four writers, Hooke, Woodward, Leigh or Whitehurst, wrote more than a few brief paragraphs, (most of which have been quoted in this paper) outlining their hypotheses. Consequently their views have been overlooked by such commentators as Adams (1938) and Rieuwerts (1984) and it seems highly likely that they had little or no effect on contemporary scientific thought let alone the mining fraternity. Quaint as some of their ideas may seem to us today it is salutary to remind ourselves that we still do not know for certain the source, mode of transport or mechanism of precipitation of ore and gangue minerals in the South Pennine Orefield. Current controversies which debate North Sea basin versus deep-seated igneous sources for Derbyshire ore forming fluids have as little effect on current mining practice as did seventeenth and eighteenth century concepts. In fifty years time today's concepts may seem as quaint and fanciful as do those of Hooke, Woodward, Leigh and Whitehurst quoted in this paper.

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