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VOLCANIC STUDIES BY MEMBERS OF THE ROYAL SOCIETY OF LONDON 1665 - 1780

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Abstract

Late seventeenth century ideas about volcanic activity were largely derived from classical sources. The *Philosophical Transactions* of the Royal Society of London provided a vehicle for publication of information about volcanoes where many ancient notions were refuted and new hypotheses suggested. Volcanic studies by members included detailed field reports, eyewitness accounts of eruptions as well as expeditions to extinct or dormant volcanic peaks, experiments with volcanic rocks, and speculation on the nature of subterranean "fires" and causes of eruptions. The development of theories concerning the formation of the columnar basalts of the Giant's Causeway is also traced. By the 1770's there appeared a general acceptance among members of the Royal Society of the igneous origin of basalt, the existence of ancient extinct volcanoes and the implications of past geologic change.

But now I will unfold
At last how yonder suddenly angered flame
Outblows abroad from vasty furnaces
Aetnaean. First, the mountain's nature is
All under-hollow, propped about, about
With caverns of basaltic piers. And, lo,
In all its grottos be there wind and air —
For wind is made when air hath been uproused
By violent agitation. When this air
Is heated through and through, and, raging round,
Hath made the earth and all the rocks it touches
Horribly hot, and hath struck off from them
Fierce fire of swiftest flame, it lifts itself
And hurtles thus straight upwards through its throat
Into high heav'n, and thus bears on afar
Its burning blasts and scattereth afar
Its ashes, and rolls a smoke of pitchy murk
And heaveth the while boulders of wondrous weight —
Leaving no doubt in thee that 'tis the air's
Tumultuous power. Besides, in mighty part,
The sea there at the roots of that same mount
Breaks its old billows and sucks back its surf.
And grottos from the sea pass in below
Even to the bottom of the mountain's throat.

Lucretius, *De Rerum Natura*, VI, 657 - 80.

For most Englishmen in the seventeenth century, the eruption of a volcano was a remote and exotic phenomenon related at second hand by travellers or in the works of classical authors such as Lucretius who penned one of the more vivid accounts of the perennial eruptions of Etna. One of the aims of the members of the Royal Society of London was "to make faithful Records, of all the Works of Nature, or Art, which can come within their reach". (Sprat, 1667: p. 61) In the *Philosophical Transactions* these reports of observations that were curious in nature or science frequently included eyewitness accounts of such highly spectacular prodigies of nature as volcanic eruptions. Among the eruptions reported were Etna in 1669 (*Phil. Trans.* No. 51, 1669, pp. 1028-34; see also v. 60, 1770, pp. 1-19); several volcanos in the Moluccas (No. 216, 1695, pp. 42-51; No.

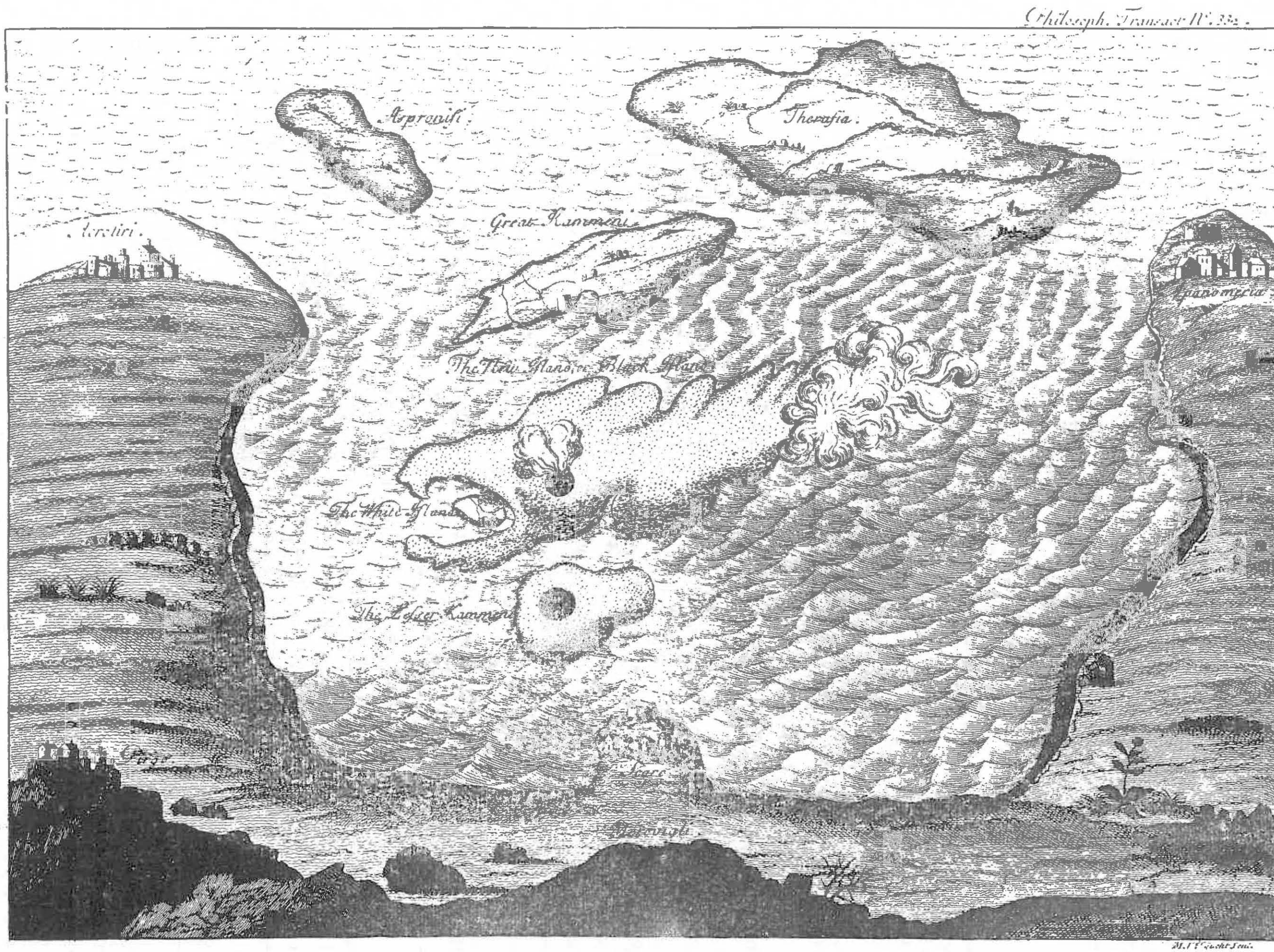

Figure 1 Plan of Santorini to illustrate Father Goree's account of the eruption in 1707. (*Phil. Trans.* No. 332, 1711, facing p. 353.)

228, 1697, pp. 529-32); and Vesuvius (No. 337, 1713, pp. 22-5; No. 354, 1717, pp. 708-13; No. 424, 1732, pp. 336-8; No. 455, 1739, pp. 237-61; v. 47, 1751-2, pp. 315-7, 409-12, 474-5; v. 50, 1758, pp. 622-3; v. 52, 1761-2, pp. 44-5; v. 57, 1767, pp. 192-200 and v. 58, 1768, pp. 1-12). There were also reports of new islands erupted from the sea at Santorini in the Aegean in 1707 (No. 314, 1708, pp. 67-8; No. 317, 1708, pp. 200-8 and No. 332, 1711, pp. 354-75) and near Terceira in the Azores in 1720 (No. 372, 1722, pp. 100-1). Detailed descriptions of the volcanic peaks of Teneriffe (No. 345, 1715, pp. 317-25; v. 47, 1751-2, pp. 353-7 and v. 55, 1765, pp. 57-60) and La Souffrière in Guadeloupe (v. 49, 1755-6 pp. 564-79) also appeared. Robert Hooke compiled a large number of accounts of eruptions for his lectures to the Society on the subject of earthquakes. (Hooke, 1705) All these accounts of volcanic activity were read with great interest and over the years a good deal of field evidence became available to members of the Royal Society.

OBSERVATIONS IN THE FIELD

Among the Prodigies of Nature, and the most surprising things which She has at any time produc'd, we may in my Opinion, very justly reckon an Island which rose up out of the Bottom of the Sea about 4 years ago, in the Bay which makes the Harbour of the Isle of Santorini in the Archipelago; especially if we consider the Situation, Manner, and all the other Circumstances of the Formation of this New Island. For what can be more surprising than to see Fire, not only break out of the Bowels of the Earth, but also to make itself a Passage through the Waters of the Sea without being extinguished? (*Phil. Trans.* No. 332, 1711, pp. 354-75).

Thus wrote Father Goree, an eyewitness of the spectacular eruption at Santorini in 1707. The eruption was heralded by earthquakes on 23 May and the appearance of "a shoal of fine pumice stone" which gradually increased in size to half a mile in circumference and 20-25 feet high by mid June. The sea was highly disturbed and strong fumes were evident. On 16 July "there rose up a Ridge of Black Stones . . . which was afterward not only the Center of the whole Island, but also of the Fire and Smoak, and great Noise, that was heard some time after". Eruptions continued, and a year later "we judged this New Island to be about 200 foot in Height 5 Miles in Circumference, and a Mile over its broadest part". The initial pumice deposits remained and were named White Island; the large proportion of the new island consisted of black lava, which Father Goree called Black Island. (Figure 1.) Eruptions continued although they were moderating at the time of writing in July 1711.

Another brief report was made of a similar phenomenon which occurred southeast of Terceira in the Azores: "an island all Fire and Smoak" and "Ashes fell on our Deck like Hail or Snow all Night". The eruption had begun in November 1720 and when observed in December a substantial island had been built up. "Prodigious quantities of Pumice-Stones and half-broil'd Fish were found floating on the Sea, for many Leagues round the Island, and abundance of Sea Birds hovering about it." (*Phil. Trans.* No. 372, 1722, pp. 100-1.)

The phenomenon of new islands was not a complete surprise. James Petiver and Father Goree quoted historical examples of this occurring at Santorini. Great Kammeni rose out of the sea in 196 B.C., and was increased in size by another eruption in 726 A.D. and again in 1427. Lesser Kammeni was formed in 1573 A.D. The new island of 1707 was in between these two. Petiver noted that Santorini itself was also "made up of burnt Rocks and pumice Stones". (*Phil. Trans.* No. 314, 1708, pp. 67-8; see also No. 317, 1708, pp. 200-8.) Father Goree quoted Pliny's opinion that Santorini, once called Thera, also rose in the same manner. (It is possible that the collapse of the caldera of the ancient Thera was the source of Plato's tale of the lost Atlantis.)

The historical evidence of previous eruptions did not explain how, or why, they occurred and Father Goree speculated on this:

I know very well that Subterranean Fires, when pent up in a narrow Passage, are able to raise up a Mass of Earth as large as an Island : But that this should be done in so regular and exact a manner, that the Water of the Sea cannot always penetrate to and extinguish them; that the Fire itself, after having made so many Vent-holes and Passages should notwithstanding retain a force sufficient to raise up so great a Mass; and in fine, after the Fire is extinct, that this great Mass should not fall or sink down again thro' its own weight but still remain of the same Height that the Fire had raised it; This is what to me seems more surprising than anything that has been related of Mount Gibel [Etna], Vesuvius, or any other Volcano.

Nicholas Witzen of Amsterdam passed on to the Royal Society some letters describing eruptions of volcanos in the Moluccas. The account of an expedition to the top of an active peak in Ternate contains a good description of the formation of splatter debris: "at last we saw that most terrible and fearful Opening wherein there is an inexpressible Noise, and out of which the smoak came forth". Some bombs were still being thrown out, and there were strong fumes.

Round about the Hole lyes scattered much of the matter that hath been cast forth; and it is perceivable that it must be soft when it somes out, because it falls flat, according to the figure of the place where it falls. The colour of it is dark green, not clear, but somewhat gray; and this matter generally does burst or separate itself as the Dung of a Cow. There are of this both great and small pieces, now turned into Stone, being inwardly blackish and spongeous, mixt with white spots. (*Phil. Trans.* No. 216, 1695, pp. 42 - 8).

The account of the eruption in the island of Sorea described the formation of a caldera. Intermittent eruptions of "fire and smoke" accompanied by earthquakes over six or seven weeks culminated in the eruption of "not only a most prodigious Flame but also such a black and Sulphurous Vapour" that a nearby village was covered with ash. This was "followed by a whole stream of burning Brimstone". Gradually parts of the mountain sank down into the burning lake in the crater and the sides continued falling in, increasing the size of the caldera until it comprised almost half the island. The writer also quoted other examples of "burning mountains" in the area which had gradually filled up and "quenched themselves". (*Phil. Trans.* No. 216, 1695, pp. 49-51.)

John Andrew Peysonnel provided an account of fumaroles on La Souffrière, or Brimstone Hill, in Guadeloupe:

there is no grass to be seen, nothing but sulphur and calcined earth; the ground is full of crevices, which emit smoke or vapours; these cracks are deep and you hear the sulphur boil. Its vapours rising yield very fine chemical flowers, or a pure and refined sulphur . . . and you breathe an intolerable smell of brimstone.

The summit of the mountain itself was "a very uneven plain, covered with heaps of burnt and calcined earth of various sizes; the ground smokes only at the new funnel, but appears to have formerly burnt in many places . . ." Having already described the mountain as "a kind of truncated cone" Peysonnel went on to speculate on the former outline of the summit: "It looks as if it had formerly been a conical figure, and had lost its top by earthquakes". (*Phil. Trans.* v. 59, 1755-6, pp. 564-79.)

The spectacle of a lava flow, of masses of fiery molten material pouring down a mountainside, fascinated eyewitnesses and some very graphic accounts appeared in the reports of eruptions. Some "Inquisitive English Merchants, now residing in Sicily" provided this description of a lava flow from Etna in 1669:

it was nothing else, but divers kinds of Metals and Minerals rendered Liquid by the fierceness of the Fire in the bowels of the Earth, boyling up and gushing forth, like the water doth at the head of some great River; and having run in a full body for a good stones cast or more, the extremities thereof began to crust and curdle, becoming when cold, those hard porous stones which the people call *sciarri* having the nearest resemblance to huge cakes of sea cole [i.e. coal carried by sea from Newcastle to London]; full of a fierce Fire. These came rolling and tumbling over one another, and where they met with a bank would fill up and swell over, by their weight bearing down any common building, and burning up what was combustible. The chief motion of this matter was forward, but it was also dilating itself, as a Flood of Water would do on even ground, thrusting out several Armes, or Tongues, as they call them. (*Phil. Trans.* No. 51 1699, pp. 1028-34).

The lava flows of Vesuvius also provided much material for the thoughtful observer. Joseph Valletta noted that the flow rate of the "fiery river" in the 1707 eruption depended on its liquidity or density, and that as it gradually hardened into rock, it developed "spongy rocks" on the surface while those below were "much harder and more solid". (*Phil. Trans.* No. 337, 1713, pp. 22-5.) An observer of the 1737 eruption thought the lava flowed much more slowly than previously noted:

though in a great Declivity, these great Masses must be much retarded in their Motion, by their large unequal Points or Angles; besides the Glewyness of the Bitumen as it cooled, would very much impede a quick motion. (*Phil. Trans.* No. 455, 1739, pp. 252-61).

Mr Richard Supple commented on the 1751 eruption: "The lava seems to be much more charged with metals and fire than any of the former flows". (*Phil. Trans.* v. 47, 1751-2, pp. 315-7.) Mr John Parker wrote of the same eruption that the lava

seems to be composed of iron, antimony, sulphur and salts, and is not always of the same colour, taste, etc. in every place. The thing I can compare it to most is the large cinders thrown out of your great iron works, but covered over in many places with the above salts and sulphur. (*Phil. Trans.* v. 47, 1751-2, pp. 474-5).

Mr J. Edens made similar comments on the rocks at the top of the Peak of Teneriffe. They were "all extream heavy" and some "look like Dross that comes out of a Smith's Forge, which without doubt was occasioned by the extream heat of the place they came from." (*Phil. Trans.* No. 345, 1715, pp. 317-25.) Parker also noted that a mass of cool lava thrown onto red hot lava "rebounded like a ball". Lava tunnels were reported by Sir William Hamilton on Etna (*Phil. Trans.* v. 60, 1770, pp. 7-8), by Edens on the Peak of Teneriffe (*Phil. Trans.* No. 345, 1715, pp. 317-25), and by Peysonnel on La Souffrière (*Phil. Trans.* v. 49, 1755-6, pp. 564-79) but no comment on their formation was put forward.

Vesuvius was by far the best known and most frequently reported volcano. The sight of it in eruption was a memorable event of the "grand tour" in the eighteenth century. One such observer described the crater during the 1751 eruption.

The bottom of the great crater which was before an indurated scurf of bitumen and sulphur, is now full of large rents or openings, cover'd over with sal ammoniac, nitre and sulphur. The little mountain, from whence before this eruption, the smoke and flame issued, and which was within the great crater, is now intirely sunk down, and a horrible fiery gulph appears where it stood . . . The concreted scurf at the bottom was liquefied and boiling in several places . . . (*Phil. Trans.* v. 47, 1751-2, pp. 409-12).

A similar phenomenon occurred on 24 January 1758.

On that day it suffered two internal fractures which intirely changed its appearance within the crater, destroying the little mountain, that had been forming within it for some years, and was risen above the sides; and throwing up by violent explosions, immense quantities of stones, lava, ashes and fire . . . (*Phil. Trans.* v. 50, 1758, pp. 622-3).

The most detailed accounts of the behaviour of Vesuvius came from Sir William Hamilton, His Majesty's Envoy Extraordinary at Naples. Sir William took it upon himself to "report the many extraordinary appearances that have come under my own inspection, and leave their explanation to the more learned

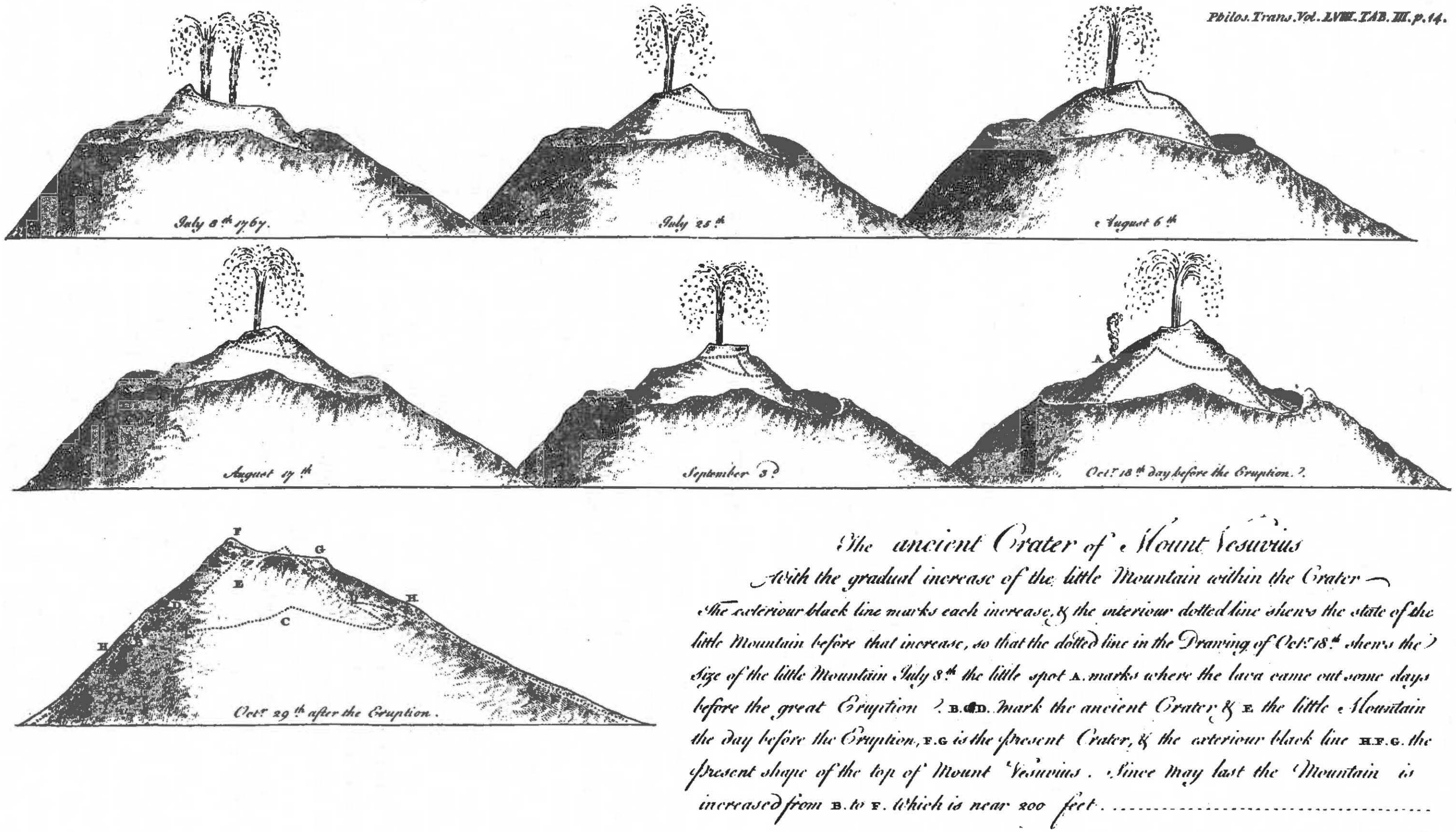

Figure 2 Sir William Hamilton's diagrams of Vesuvius. (*Phil. Trans.* v. 58, 1768, facing p. 14.)

in natural philosophy". Although, as Sleep (1969: p. 321) commented, "Hamilton pursued his studies of geology as a hobby, there was nothing amateurish about his methods in geology". His letters to the Royal Society provided the finest field reports to date of the behaviour of volcanos and Vesuvius in particular he came to regard almost as his own personal volcanological laboratory. Sir William was well aware of the differing nature of materials ejected from volcanoes. The material covering Herculaneum he noted, was different from that which buried Pompeii: "very probably the matter that covers Pompeii proceeded from a mouth or crater, much nearer to it than is the great mouth of the volcano, from whence came the matter that covers Herculaneum". Sir William also considered the contact of fire and water in a volcanic eruption. He described the frequent explosions of Vesuvius and

> a continued subterraneous and violent rumbling noise . . . I have imagined that this extraordinary noise might be owing to the lava in the bowels of the mountain having met with a deposition of rain water, and that the conflict between the fire and the water may, in some measure, account for so extraordinary a crackling and hissing noise. (*Phil. Trans.* v. 58, 1768, p. 7).

His most significant contribution to the field study of Vesuvius was the series of detailed drawings of the development of the cone within the crater during the 1767 eruption. (Figure 2.)

> From my villa, situated between Herculaneum and Pompeii, near the convent of the Calmaldolese, I had watched the growing of this little mountain, and by taking drawings of it from time to time, I could perceive its increase most minutely; I make no doubt but that the whole of Mount Vesuvius has been formed in the same manner; and as these observations seem to me to account for the various irregular strata, which are met with in the neighbourhood of volcanos, I have ventured to enclose for your Lordship's inspection a copy of the abovementioned drawings. (*Phil. Trans.* v. 58, 1768, p. 3).

EXPERIMENTS WITH VOLCANIC ROCKS

Among the many and varied items received for the repository of the Royal Society were specimens of volcanic rocks. Some "English Merchants" contributed the following items collected after the eruption of Etna in 1669: "Ashes" from various parts of the mountain; "Cinders" locally termed "sciarri" (scoria) some black, some crusted with brimstone, some red, mostly light in weight but one kind was "very solid and ponderous which seems to be made up a conflux of divers Minerals melted together" and a "Piece of Sal Ammoniack". They expressed the hope that examination of these specimens would lead to an explanation of the cause of the eruption, especially if they were found to be easily flammable or quickly kindled by falling stones. (*Phil. Trans.* No. 52, 1669, pp. 1041-2.) Unfortunately no report of analysis of these specimens appeared in the *Philosophical Transactions*. Sir William Hamilton also sent to the Society samples of "some very curious salts and sulphurs" and "some lava, and cinders, of this eruption . . . It is very extraordinary, that I cannot find, that any chemist here has ever been at the trouble of analysing the productions of Vesuvius". (*Phil. Trans.* v 57, 1767, pp. 199-200.)

It is a pity that Sir William did not peruse earlier issues of the *Philocophical Transactions* for in 1739 (No. 455, pp. 237-52) there appeared "A Letter from his Excellency Nicholas-Michael d'Arragona, Prince of Cassano and F.R.S." which reported on some experiments conducted by the Naples Academy of Science on material ejected by Vesuvius during the eruption of 1737. These experiments included pounding of rocks and application of the lodestone to ascertain that they contained iron. Some of the specimens contained "some few Veins of Gold, in others of Silver, but insensible; and in others which are heavy, there is some Antimony". Variation in density and weight of samples taken from different levels in a lava flow were also noted. The lava samples, reduced to a fine powder and viewed through a microscope, appeared very like the "Sand of Ischia and is very proper for Writing Sand: Whence I conjecture that the Sand is nothing else but the same Matter, for a long time comminuted by the Action of the Sea". More elaborate exeriments with specimens of "salts" included analysis by crystallisation and the conclusion that these contained "a genuine and efficacious Salt Ammoniac, with insensible portions of Nitre and sea Salt". Mixing of the Sal Ammoniac with "Spirit of Vitriol and Spirit of Salt" produced no "fermentation" and mixing with "Oil of Tartar" produced no "ebullition" and therefore it was concluded to be "a neutral salt". The "salts" when placed on red coals "did not crepitate like Sea Salt, but it boiled and swelled, and after evaporating it dried up". These salts had a pungent taste, "a bituminous smell of brimstone" and were coloured variously from white, yellow to a blackish tint. Further experiments included mixing with a variety of other materials, as well as injecting a solution of it into the vein of a dog which died four hours later following "universal convulsions".

Experiments were also conducted by the Naples Academy to determine the nature of the "many pernicious Damps" which arose from cavities and fissures in former lava flows. Temperature readings were taken and it was noted that a lighted torch was extinguished in them. The most perplexing observation was that the damps or vapours arose only from old lava flows, not the most recent, as might have been expected if they were the result of "the Action of the Fire". This anomaly was explained thus:

As the cooling of the burning Matter began at the Surface, we may think that the more subtle heterogeneous Particles, upon the closing of the Pores at the Surface, remained in Quantities buried in the lower Parts of the Matter; which, in Process of Time, becoming acutangular and of deleterious Figures, yet cannot offend while imprisoned : But in new Eruptions, wherein the Shocks given to the Matter produce many Fissures, the Damps, meeting with less resistance there, issue forth : As when the Air is a long time pent up in some Hollow, upon giving it Vent, it generally comes out in a pernicious Vapour.

One misleading attempt to analyse the nature of pumice was published. Anthony van Leuwenhoek acknowledged the current belief that pumice was found in the sea and its lightness was explained because it "is calcined by the Fire before it is thrown out of the Burning Mountains, after such a Manner as to fit it for swimming on the top of the Water". He doubted whether the cavities in pumice could be produced by "fire", and that if it were thrown out of a volcano it would still be hot when it fell into the sea, and, on analogy with a piece of "hot wood coal", must sink. On the basis of his microscopical observations of sponges, corals and pumice stones, he reached the somewhat surprising conclusion that they all had a similar origin in the sea. (*Phil. Trans.* No. 304, 1705, pp. 2158-63.)

Dr Heberden was fascinated by "the soil mixed with brimstone" and "a lot of red clay" and also "salts showing white and greenish colours" found in the crater of the Peak of Teneriffe. (*Phil. Trans.* v. 47, 1751-2, pp. 353-7.) He reported on various experiments with the salt which he identified as "natron or nitrium of the ancients" also called "fossil alkali, which is the basis of sea salt". He was perplexed by the manner of its occurrence in the crater of a volcano.

There is no difficulty in conceiving how brimstone may be forced up by subterraneous fires; and it is no uncommon thing to find it in other places : but it is not so easy to understand how a salt of so fixed a nature, as this is, should be sublimed to such a height without being cooled and fixed long before it arrives at the surface of the earth, where no sensible heat is perceived. Neither am I able to explain how it happens, that a substance, so easily melted in water, is not dissolved and washed away, as fast as it can be produced, by the dews, and rains and melted snow. (*Phil. Trans.* v. 55, 1765, pp. 57 - 60).

Although many of these early "experiments" with volcanic rocks were little more than fumbling attempts at analysis of the components of rock specimens, nevertheless, they were embarked upon in the true spirit of scientific enquiry, in the hope of elucidating further the nature of the material and perhaps the source of the "fires" that produced these mysterious rocks and minerals.

THE CAUSES OF VOLCANIC FIRES

To the Greeks, earthquakes and volcanoes had a similar origin. Aristotle said they were caused by wind or "dry exhalation" entering the earth, or enclosed within the earth and seeking an exit. Such wind was "compressed into a smaller space and so gets the upper hand, and then breaks out and beats against the earth and shakes it violently". (*Meterologica* II, 8.) Other causes attributed by the Greeks and quoted by Aristotle included the idea of Democritus that excessive amounts of rain water moving in the earth caused quakes. Anaximenes thought that breaking up of the earth in times of drought or heavy rain was the cause. A volcanic eruption was the outward and visible sign of the bursting forth of the subterranean wind that caused an earthquake.

This happened lately near Heracleia in Pontus and some time past at the island of Hiera, one of the group called the Aeolian islands. Here a portion of the earth swelled up and a lump like a mound rose with a noise : finally it burst and a great wind came out of it and threw up live cinders and ashes which buried the neighbouring town of Lipara and reached some of the towns in Italy. The spot where this eruption occurred is still to be seen. Indeed this must be recognised as the cause of the fire that is generated in the earth : the air is first broken up in small particles and then the wind is beaten about and so catches fire. (*Meteorologica* II, 8).

Not surprisingly, Aeolus, Greek god of the winds, had his abode in the fiery caverns of the Aeolian islands.

The Greeks also acknowledged a "common belief in subterranean accumulations of sulphur and other combustible substances". (Geikie, 1905: p. 18.) The passage of subterranean winds also set fire to these combustible substances and where this fire broke through the surface of the earth, volcanoes occurred. The idea of volcanoes as safety valves, the escape hatch for imprisoned wind, vapour and burning matter which caused disastrous earthquakes, was an integral part of ancient Greek ideas on the nature of volcanoes.

Late seventeenth century ideas on the causes of volcanoes and earthquakes which owe much to the ancient Greeks were summarised in Varenius' *General Geography*.

Those Countries which yield great store of Sulphur and Nitre are by far the most injured and incommoded by earthquakes; where there are such Mines they must send up Exhalations, which meeting with subterraneous Caverns, they must stick to the Arches of them, as Soot does to the sides of our Chimnies, where they mix themselves with the Nitre or Saltpeter . . . and so makes a kind of Crust which will very easily take Fire. There are several ways by which this Crust may take Fire, *viz*. 1. By the inflammable Breath of the Pyrites, which is a kind of Sulphur that naturally takes Fire of itself. 2. By a fermentation of Vapours to a degree of Heat equal to that of Fire and Flame. 3. To the falling of some great Stone, which is undermined by Water, and striking against another, produces some Sparks which set Fire to the combustible Matter that is near; which being a kind of natural Gunpowder, at the appulse of the Fire, goes off, (if I may so say) with a sudden Blast or violent Explosion . . . Burning Mountains and Vulcanos are only so many Spiracles serving for the Discharge of this subterranean Fire, when it is thus preternaturally assembled.

Where the "Structure and Conformation of the interior Parts of the Earth" were such as to permit the fire to pass unimpeded, eruptions occurred without quakes; but where an exit was obstructed in any way "it heaves up and shocks the Earth, till it hath made its ways to the Mouth of the Vulcano". (Varenius, 1736: v. 1, p. 155.)

The idea of spontaneous firing of the "Pyrites" was based on Greek ideas of combustible material in the earth, and dry exhalations in the earth and air. These ideas were given a seventeenth century form by Martin Lister who attempted to assign to the Pyrites the causes of earthquakes and volcanic eruptions as well as thunder and lightning. Lister coined the phrase "Inflammable Breath of the Pyrites" which he defined as "Sulphur *ex tota substantia*". He accepted that the earth was "more or less hollow" because of the many "Natural Cavities or Chambers" reported by miners. He also noted that "these subterraneous Cavities are at certain times and in certain seasons full of inflammable Vapours; the Damps in our Mines sufficiently witness; which fired, do everything as in an Earthquake, save in a lesser degree". He further defined a Pyrite as any sulphurous mineral, or ore, including coal, and suggested that "the Pyrites of the Vulcanos or burning Mountains may be more Sulphureous than ours". This explained why England had no volcanoes and rarely experienced earthquakes, while both were frequent in the Mediterranean. To quell arguments against spontaneous firing of the Pyrites, Lister quoted the spontaneous combustion of wet hay, the natural heat of animals or men, which increases during a fever, and the apparently spontaneous firing of damps in mines. In answer to the suggestion that volcanoes could be fired by the sun, he quoted "Hecla placed in so extream cold a Climate". Nor could volcanoes have been fired originally by man as they probably existed before man appeared on earth. Lightning, since it too was caused by firing of the Pyrites in the air, was also dismissed. "It remains therefore (very probably) that they were kindled of themselves." (*Phil. Trans.* No. 157, 1684, pp. 512-9.)

Martin Hortop, writing on the fires and earthquakes of Vesuvius and Etna, considered that the combustible matter of these areas consisted of "Nitre mixt with some other Minerals and Sulphur". He went on to describe a frequently quoted chemical experiment which was thought to reproduce conditions in an erupting volcano.

He that has seen the way of making Salt of Tartar by Deflagration, where you mix an equal quantity of pulveriz'd Nitre, has seen an exact Type of these burning hills : For after each spoonful you put in the burning Crucible, arises first a thick black Smoak, after which the fired Mineral boils up as if it would over run the top of the Crucible. (*Phil. Trans.* No. 202, 1693, pp. 827 - 9).

Most of the early accounts of volcanic eruptions which appeared in the *Philosophical Transactions* contained little speculation as to causes and tended by implication to accept some form of firing of combustible materials in the earth. Father Goree attributed the eruption at Santorini to a "Mine of Sulphur" being consumed by fire and considered that the continued eruption over such a long period was caused by the volcano getting "new force by other Veins of Sulphur which take fire at a greater distance". (*Phil. Trans.* No. 332, 1711, pp. 354-75.) The writer of the reports on the volcanoes of the Moluccas suggested that they "are beneath consumed by the same fire which joyneth the spacious openings together". On the basis of the quantity of material ejected, he speculated on the vastness of the inner cavities of these mountains. (*Phil. Trans.* No. 216, 1695, pp. 49-51.)

Joseph Borelli, whose book on the eruption of Etna in 1669 was reviewed in the *Philosophical Transactions* (No. 75, 1671, pp. 2264-8), disagreed with classical views of volcanism, or as his reviewer put it, "the imperfect Meteorology deliver'd by the Ancients of this Mountain". He suggested there were no vast cavities in the mountain but, on the contrary, such spaces would be filled up, even compressed, by the considerable weight of the mountain. He discussed the source of "Subterraneous Heat, and deduceth the cause of it from some concrete oleaginous and fatty substances, as sulphur, bitumen and oyl, easily reducible into flame" on analogy with the ignition of gunpowder. The "Aetnaean Fires" were most likely kindled "as Quick Lime is heated by the Affusion of Water; whereupon he sheweth how Earthquakes, Flames and Conflagrations may have ensued". Borelli also rejected the idea that Etna's fires were perpetual and noted that there were periods of cessation and rekindling, although his reasons for this belief are not included by the reviewer who referred the reader to the book itself for "many other considerable remarks and reflections, too many to be here recited".

Borelli's treatise was often quoted and in general was regarded as authoritative. Edward Berkeley, who observed an eruption of Vesuvius, took issue with one of Borelli's theories however.

I saw the fluid Matter rise out of the Centre of the Bottom of the Crater, out of the very middle of the Mountain, contrary to what Borellus imagines, whose method of explaining the Eruption of a Volcano by an inflexed Syphon, and the Rules of Hydrostaticks, is likewise inconsistent with the Torrent's flowing down from the very Vertex of the Mountain. (*Phil. Trans.* No. 354, 1717, pp. 708 - 13).

The analogy of a volcanic eruption with the explosion of gunpowder was an apt one which did not radically contradict the traditional idea of subterranean fires, merely added a new dimension to it. An "English Gentleman at Naples" who had read Dr Burnet's *Sacred Theory of the Earth*, likened the 1737 eruption of Vesuvius to the explosion of gunpowder.

The Earth of this Country is, no doubt, greatly compounded of Sulphur and Nitre, from whence Dr Burnet hath fixed it for the Beginning of the General Conflagration; though he has, out of a particular Spite to the people of Rome, laid the Commencement of it there. The great Quantities of Sulphur and Nitre are, to be sure, the Operators of these great Explosions, Lightnings, Bombs, Bellowings and Expulsions of all this Matter; and Nature can certainly make much stronger and more elastic Gunpowder than Mankind; else those great massy Bodies of Metals could not be thrown up with that vast Force, to that great Height. (*Phil. Trans.* No. 455, 1739, pp. 252 - 61).

Explosions of gunpowder, and perhaps Stukeley's theory of electricity (*Phil. Trans.* v. 46, 1749-50, pp. 641-6, 657-9; see also Adams, 1938, pp. 411-2) as the cause of earthquakes, influenced Peysonnel's conjectures on a former earthquake and eruption of La Souffrière in Guadeloupe.

Perhaps the Volcano having been fired by lightning, the salts of the earth joined with the sulphur produced the effect of gunpowder, and occasioned this dreadful earthquake. The mountain having split, cast forth ashes and sulphureous matter all around, and from that time no earthquake has been felt on the island. (*Phil. Trans.* v. 49, 1755 - 6, p. 569).

Sir William Hamilton was also interested in electricity: "I am convinced that the smoke of volcanos contains always a portion of electrical matter, which is manifest at the time of great eruptions". (*Phil. Trans.* v. 61, 1771, p. 40.) However, he regarded lightning around a volcano as one of the interesting phenomena to be observed during an eruption and did not advance this as a cause of volcanic activity.

There is an echo in Peysonnel's account of the idea of volcanoes as safety valves. Similarly, Father Goree had expressed surprise that earthquakes recurred at Santorini even after the fire had reached the surface. Sir William Hamilton, classical scholar that he was, embraced similar ideas.

I am convinced that it has often happened that subterraneous fires and exhalations, after having been pent up and confined for some time, and been the cause of earthquakes, have forced their passage, and in venting themselves formed mountains of the matter that confined them, as you will see was the case near Puzzole in the year 1538, and by evident signs has been so before in many parts of the neighbourhood of Puzzole; without creating a regular volcano.

Sir William went on to remark that in "a comparison between the earth and a human body, one might consider a country replete with combustibles occasioning explosions (which is surely the case here) to be like a body full of humours". Unless these humours concentrate and discharge from the body in one place, the body remains "agitated". This image was derived directly from Aristotle's *Meteorologica.*

In a similar manner one may conceive Vesuvius to be the present great channel, through which nature discharges some of the foul humours of the earth; when these humours are checked by an accident or stoppage in this channel for any considerable time, earthquakes will be frequent in its neighbourhood, and explosions may be apprehended even at some distance from it. (*Phil. Trans.* v. 61, 1771, pp. 10 - 11).

John Michell in his "Conjectures" on earthquakes (*Phil. Trans.* v. 51, 1759-60, pp. 566-634) accepted "that earthquakes owe their origin to some sudden explosion in the internal parts of the earth" caused by subterranean fires. "These fires, if a large quantity of water should be let out upon them suddenly, may produce a vapour, whose quantity and elastic force may be fully sufficient for the purpose". One of his reasons for advancing this conjecture was that "those places that are in the neighbourhood of burning mountains, are always subject to frequent earthquakes; and the eruptions of those mountains, when violent are generally attended with them". The fires of volcanoes "are fires of the very same kind with those, which I suppose to be the cause of earthquakes". While Michell made a major contribution to the understanding of earthquakes in this paper, he added little to contemporary ideas about the causes of volcanic activity. The contact between water and subterranean fires as a cause of explosion had been postulated by the ancient Greeks.

The spectacle of an erupting volcano still posed more questions than provided answers about the nature of the interior of the earth. One observer of the 1751 eruption of Vesuvius summarised the problem.

The whole is such a stupendous prodigy of nature as must puzzle the wisest philosophers to account for. Why does this subterraneous cauldron boil over only at certain periods of time ? And whence is it supplied with combustible *pabulum* for many hundreds or thousands of years ? (*Phil. Trans.* v. 47, 1751 - 2, pp. 409 - 12).

THE GIANT'S CAUSEWAY AND OTHER PILLARS OF BASALT

The columnar basalts of the Giant's Causeway in County Antrim, Northern Ireland, were first described scientifically by Sir Richard Bulkeley who had his information second hand from one who was "a Scholar and a Traveller". He noted that the surrounding country was all made up of a similar sort of rock.

This whole Causway consists all of Pillars of perpendicular Cylinders, Hexagones and Pentagones of about 18 and 20 Inches Diameter, but so justly shot one by another, that not anything thicker than a Knife will enter between the sides of the Pillars.

He apologised for the use of the term cylinders: "Pardon the Impropriety of the Word" and went on to comment "that the Cylinders do not consist of Joints is manifest from This, that the pieces so broken off, have their bottoms as often convex or concave as flat and even". He also noted that some pillars "are also four-squared upon the same Shore". (*Phil. Trans.* No. 199, 1693, p. 708.)

The following year the Rev. Dr Sam Foley provided further details of the dimensions of the structure and of the pillars themselves.

Figure 3 Columnar basalt, Giant's Causeway, County Antrim, Northern Ireland. (Photo: Evelyn Stokes.)

some are very long and higher than the rest, others short and broke, some for a pretty large space of equal height, so that the tops make an even plain Surface, many of them imperfect, crack'd and irregular; others entire, uniform, and handsome, and these of different shapes and sizes: We found none at all Square but almost all Pentagonal, or Hexagonal; only we observed that a few had seven sides; and many more Pentagons than Hexagons; but they were all irregular for none that we could observe had their sides of equal breadth; the Pillars are some of them 15, some 18 Inches, some two Foot in Diameter . . .

He also commented on the jointing of the columns. "These Joynts are not always placed alike, for in some Pillars the Convexity is always upwards, and in others it stands always downwards." He also remarked on the closeness of the vertical joints between columns: "and though some have five sides, and others of them six, yet the Contextures of them are so adapted, that there is no vacuity between them . . ." Some of the columns were "thicker than others, according as 'tis necessary to make them lye close to those various Figures, but every single Pillar doth retain its own Thickness, and Angles and Sides from top to bottom . . ." The paper was accompanied by a not very accurate bird's eye view of the Causeway by one Christopher Cole. (*Phil. Trans.* No. 212, 1694, pp. 169-75.)

The Rev. Dr Thomas Molyneux was fascinated by these accounts:

This mighty large Pile of Stony Columns that goes under the name of the Giant's Causway, I take not only to be as Remarkable a Natural Curiosity of its sort as this Country affords, but perhaps as may be met with in Europe . . .

Although unable to visit it himself, Molyneux collected as much information as he could and reported to the Society. (*Phil. Trans.* No. 212, 1694, pp. 175-82; No. 241, 1698, pp. 209-23.) He despatched "one Mr Sandys, a good Master in Designing and Drawing of Prospects, to go into the North of Ireland and upon the Place take a genuine and accurate Figure of the whole Rock, with the natural Posture of the Hills and Country about it". This "Prospect" later appeared in the *Philosophical Transactions* (No. 235, 1697, facing p. 777; see Figures 4 and 5).

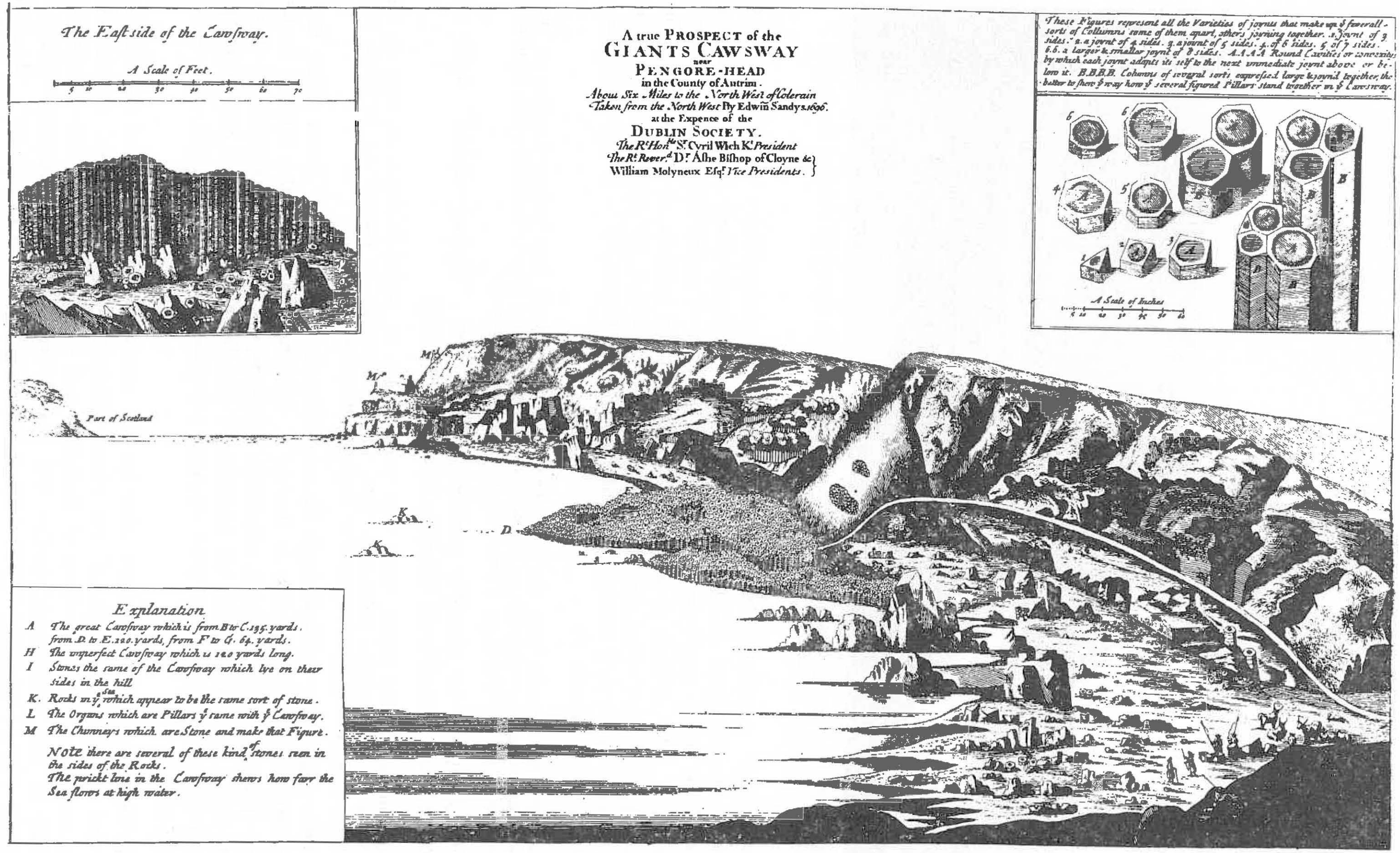

Figure 4 Edwin Sandys' Prospect of the Giant's Causeway. (*Phil. Trans.* No. 235, 1697, facing p. 777.)

Figure 5 The Antrim coast and Giant's Causeway area shown in Sandys' Prospect. (Photo: Evelyn Stokes.)

Molyneux speculated on the nature of this extraordinary "Production of Nature". He disposed of suggestions that it was constructed by man because part of it was under water and there was no evidence of cementing of the columns or marks of "the strokes of Tools or Chissels in the Surface of any part of the Stone; that there are other parcels of the like Stone which lye still in their Native Beds, as they were first produced in the adjoyning Mountain". In these circumstances it was difficult to

imagine that Men could have the least Design in putting all this useless Lumber in this most wonderful manner together in so Remote and Desolate a place. And for such, that will ascribe it to Giants or Daemons, I think do not deserve an Answer.

He went on to consider analogies with other "figured stones" such as "Astroites" or a sort of fossil bamboo, and concluded that

nothing among all the Fossil Tribe that I have seen or read of, comes so nigh in all respects, in its Formation, Substance, Size, way of Growth, or manner of Standing etc. to the Columns whereof 'tis composed, as the Lapis Basaltes Misenus . . .

This name was derived from its resemblance to a similar "great large Bed within three Miles of Dresden in Saxony". Molyneux labelled the Antrim rocks "Lapis Basaltes vel Basanos maximus Hibernicus" thus distinguishing Irish basalts from Misnean basalts on account of the distinctive ball and socket jointing and the supposed lack of four squared columns. (*Phil. Trans.* No. 212, 1694, pp. 175-82.)

In his second paper, written after he had received Sandys' view of the Causeway and detailed diagrams of the rocks, Molyneux corrected and refined his earlier remarks, as well as those of Bulkeley and Foley. He noted that "there are not only in this Pile Quadrangular, but also Triangular and Octangular Pillars" and there was no evidence "there were more Pentagons than Hexagons". He also reported that the Causeway was at least 75 feet longer than it was said to be, not including the unknown extent below sea level. Other similar structures were also to be found in the same area. He confirmed his identification of the rock as basalt, quoting descriptions of similar rocks from Pliny, Kentmannus and Georgius Agricola. The range of sides from three to eight "shews it to partake still more of the Nature of the Misnian Basaltes". Having reached a correct identification and collected as much accurate information as he could, as befitted the scientific methods established by the Royal Society, Molyneux refrained from further speculation.

But it were easy to give another Conjecture of this odd Appearance, were I not better pleased to observe and set down the History of Nature as it truly is, than to amuse myself and others by making vain and uncertain Guesses at the hidden Causes of its Phaenomena. (*Phil. Trans.* No. 241, 1698, pp. 209 - 23).

The nature and origin of columnar basalts was not discussed again in the *Philosophical Transactions* until 1748. The Rev. Richard Pococke, Archdeacon of Dublin, was also fascinated by the Giant's Causeway and made at least two visits to the area and transmitted his findings to the Royal Society. (*Phil. Trans.* v. 45, 1748, pp. 124-7; v. 48, 1753-4, pp. 226-38.) In the first paper he confirmed earlier observations on the dimensions and layout of the Causeway. He was particularly struck by the stratification of the cliffs of the area.

I thence observed, that there runs all the way a Stratum from the Bottom of black Stone, to the Height, as well as I could conjecture, of about 60 Feet, divided perpendicularly at unequal Distances by Stripes of a reddish Stone, looking like Cement, and about 4 or 5 Inches in Thickness. Upon this there is another Stratum of the same black Stone, divided from it by a Stratum 5 Inches thick of the red. Over this another Stratum of Stone ten Feet thick divided in the same manner; then a Stratum of the red Stone twenty Feet deep; and above that a Stratum of upright Pillars. Above these Pillars lies another Stratum of black Stone 20 Feet high; and above this again another Stratum of upright Pillars rising in some Places to the Top of the Cliffs, in others not so high, and in others again above it, where they are called the Chimneys.

This description corresponds well with the structure of successive layers of basalt lavas, interbasaltic red zones of laterite, bauxitic clay, lithomarge and bole, the products of weathering of basalts under tropical conditions, and the dyke systems of the Antrim coast outlined by Tomkeieff (1940: pp. 95-105). Pococke also noted variations in thickness within a stratum of pillars and the effects of erosion which had laid bare a lower stratum which comprised the Causeway itself.

Pococke did not however realise the volcanic origin of these rocks. He was misled by the horizontal strata into assuming a sedimentary origin for them. This is not surprising as the principles of deposition of sedimentary strata had already been laid down by Nicholas Steno, and the deposition of rocks from a former fluid state was an integral part of Woodward's theory of the earth which gained wide popularity in the early eighteenth century. (See Stokes, 1969.)

In his second paper Pococke tackled the question of deposition of the basaltic columns. He assumed that all the strata in the area were laid down from a former fluid state and was particularly impressed by the concavities and convexities of the joints in columns. He elaborated his theory of crystallisation from a liquid:

that the several parts of these pillars were at first formed either in the shape of a cylinder, with the upper end in a spherical figure, if not both ends; or that they were either spherical or oblate spheroids . . . For, being composed of crystal of six sides, and spar of three, and of a very fine black sand, it may be supposed, that, as the crystals and spars united, and formed an irregular body, the fine black sand filled up the interstices, and formed such cylindrical bodies, as yet soft, but in thin horizontal laminae or plates like talc, as they mostly appear to be.

Thus the stratum was built up from the base, while motion continued in the contiguous fluid matter above. Over a period of time some of the particles of matter which compose these pillars, being disengag'd from the particles of water ceas'd to move, and form'd the parts of these pillars . . . so much being formed only at once, or in a very short time as extends to the first joint: that then, either by a change of season, or some other accident, so much more water mixed with these particles, as prevented their continuing to form themselves into such a shape, and gave the former motion: that afterwards, the decrease of the water might again be the cause of the former effect; and so on, till the intire pillars were formed; and the top of the last formed being convex, that, which was formed upon it would probably be concave, and fit to it, either by its gravity, or by being softer . . . we suppose the gravitation of the second stratum above the first joint to operate in such a manner on that which was first formed and still soft, as to press it down; and so eight stones being round one stone, would naturally press the middle stone into an octagon.

No-one challenged Pococke's attempt to explain the columnar jointing of the Antrim basalts. Indeed, his hypothesis was supported by Mr Abraham Trembley in his "Remarks on the Stones in the Country of Nassau, and the Territories of Treves and Colen resembling those of the Giant's Causeway in Ireland . . ." (*Phil. Trans.* v. 49, 1756, pp. 581-5).

Those who have made observations upon salts, and inquiries into stones, minerals and metals, know how common crystallisations are in nature. A very great variety are found in searching mountains, visiting caverns, and descending into mines. There are few of the naturalists, accustomed to these researches who shall observe the basaltes above mentioned, but will be inclined to consider them as so many crystallisations. I do not think, that the great extent of these masses, which have been discovered, and the bigness of the stones, which compose them, form any objection against this notion.

Pococke himself, now Lord Bishop of Ossory, reported on "a Production of Nature at Dunbar in Scotland, like that of the Giant's Causeway in Ireland" but offered no further suggestion as to its origin. (*Phil. Trans.* v. 52, 1761-2, pp. 98-9.) Emmanuel Mendez da Costa wrote to Pococke describing a structure of pillars "jointed exactly like those of the Giant's Causeway" on Cana Island south of Skye. (*Phil. Trans.* v. 52, 1761-2, pp. 103-4.)

The first suggestion in the *Philosophical Transactions* that columnar basalts could be of volcanic origin came from R. E. Raspe. (*Phil. Trans.* v. 61, 1771, pp. 580-3.) Raspe studied the basalts of Hesse and noted their distinctive form which seemed to have been acquired "in a different manner from that which influenced the strata and veins of other mountains". Nor were there any "marks or impressions of any organical bodies" in them. He confessed that he "was induced to attribute their origin to a watery crystallisation, which might have taken place, either at the first settling of the chaos, or at the time of a dissolution of a great part of our globe. I had said the same thing in regard to the Giant's Causeway . . ." However, on reading Desmarest's account of "the Auvergne basalts placed on beds of lavas and scoriae, just close to the opening of an extinguished volcano" Raspe found a similar juxtaposition at Habichswald in Hesse.

Hence it may be allowable to attribute with Mr Desmarest the origin of the basalts to volcanoes. This opinion is further supported from many circumstances: viz. the vitreous, and hitherto problematical substance of these stones; the want of marine bodies, and lastly the well known experiment of some melted metals, which when hardened, appear in crystallisations not unlike those of watery congelations.

Nicholas Desmarest had recognised the volcanic origin of the basalts of Auvergne in 1763, a conclusion communicated to the French Academy of Science in 1765 and published in their *Memoirs* in 1774. (de Beer, 1962; Geikie, 1905: pp. 105-75; Taylor, 1969.) In 1771, after seeing a drawing of the Giant's Causeway he remarked that the columns in cliffs of that part of the Irish coast were the work of one or several volcanoes, now extinct, like those of Auvergne. (Tomkeieff, 1940: p. 92.) There was no dispute over Desmarest's diagnosis of the origin of columnar basalt and subsequent contributions to the *Philosophical Transactions* on the subject assumed an igneous origin.

Mr James Keir had read Desmarest's memoir on the Auvergne basalts and his observations on crystallisations in glass led him to believe he had discovered an analogous situation.

Does not this discovery, of a property in glass to crystallise, reflect a high degree of probability on the opinion, that the great native crystals of *basaltes,* such as those which form the Giant's Causeway, or the pillars of Staffa, have been produced by the crystallisation of a vitreous *lava,* rendered fluid by the fire of volcanos?

He quoted Desmarest's observations that columnar basalts had almost always been found in association with other lavas, pumice and "other vestiges of the fire of volcanoes". In his discussion of crystallisations in glass, Keir had commented that "different crystallisations occur in the same kind of substance exposed to different circumstances". Differences within the same piece of glass indicated similar circumstances but perhaps "different periods in the progress of crystallisation". Basalt seemed to behave in a similar way.

The substance of which these basaltic masses consist, is generally of the same nature and appearance as the neighbouring and adjoining *lava.* It is generally compact, fusible, and of various degrees of hardness, probably according to the matters of which the vitreous mass was compounded. M. Desmarest has further observed, that the prismatic *basaltes* of Auvergne is actually a continuation, and generally the termination, of a current of *lava.* (*Phil. Trans.* v. 66, 1776, pp. 530-42; see also Smith, 1969).

John Strange embraced a similar opinion in his reports on the lavas, including columnar basalts, of the Euganean Hills of Italy. (*Phil. Trans.* v. 65, 1775, pp. 5-47 and 418-23.)

For surely the structure and other phenomena of these bodies sufficiently prove them to be crystallisations or concretions of a particular kind, and generated immediately from an igneous fluid; for they are not only peculiar to vulcanic tracts of country; but differ, in every respect, from common crystals produced from an aqueous fluid . . . basaltine crystallisations, notwithstanding the peculiarities of their figures, rather seem to form integral parts of the masses to which they adhere; and seem to acknowledge with them, one common and simultaneous origin . . .

However, Strange had some difficulty in relating the formation of basalt lavas to the explosive volcanoes such as Vesuvius and Etna.

It seems also further evident to me from the phaenomena, that prismatic basaltine crystallisations and other regularly figured volcanic groups . . . have been generated locally, and not in the midst of those violent convulsions of Nature, which are commonly assigned for the origin of vulcanic mountains in general.

Strange was puzzled by the occurrence of basalt lavas in apparent strata "which often form extensive horizontal beds, and of an equal thickness throughout" and "which lie in regular stages one above the other" forming "integral parts of the masses or mountains in which they are found". He could not see that this structure could have been formed by material "thrown up from the bowels of the earth, by subterranean explosions, like . . . the ejected entrails of Vesuvius and Etna". He could not reconcile "these tumultuary and inordinate aggregates, with the regular vulcanic organisations before described".

And though it is very possible that such organisations may sometimes take place upon the concretion of liquefied matter thrown up in vulcanic eruptions; yet, however similar they may be, from nature of their origin, I can hardly imagine they can form other than imperfect and irregular masses. For however wonderful the rivers of lava of Vesuvius or Aetna may appear to us, they, in reality, are but partial and tumultuary efforts of nature, that by no means seem adequate to the production of a Giant's Causeway, or the basaltine organisations of Auvergne and Velay, several of which continue, almost uninterruptedly, for many miles.

Such factors, Strange continued, "evince the necessity of their local origin upon a more steady and uniform principle". He could find no evidence of former cones or craters in the Euganean Hills which "are mostly terminated by regular convex summits, that form a solid mass". Undeterred, he concluded "that fused masses should regularly concrete in such a form" as a result of "the effervescent and expansive property of fire. The phaenomenon of horizontal vulcanic hills is accountable upon another principle, and seems chiefly to depend on the state of those hills before their ignition". Strange had no suggestions on the means of this "ignition" and also confessed:

It is difficult to say in what state vulcanic hills of a particular and regular structure, like the basaltine hills, for instance, may have pre-existed, before their alteration by fire, since they afford evident proofs, not only of a liquefaction, but of an entire new organisation; by which means all marks of their former characters are totally effaced.

Since columnar basalts occurred locally, it seemed reasonable that their original form was similar to surrounding formations.

It seems therefore sufficiently evident that fire not only operates locally on lapideous solids, but also in such a manner as not intirely to destroy all marks of their primary organisation and qualities, much less to alter their dispositions, and the external characters of the masses or mountains they form.

Strange did not consider the possibility of erosion of the Euganean Hills and the destruction of the ancient cones and craters he might have expected to find. He convinced himself that the basalt formations

never can have been thrown up fortuitously, from the bowels of the earth . . . but have suffered fire *in statu quo,* or locally, without the least appearance of subversion or change of place . . . subterraneous explosions and eruptions are merely accidental phaenomena, that are by no means essential to the production of all vulcanic mountains, as has been commonly imagined.

Sir William Hamilton had no such reservations about the formation of columnar basalts and regarded the occurrence of basalt lavas as certain evidence of the existence of ancient volcanoes. In a "most delightful passage up the Rhine from Bonn to Mayence" he noticed several peculiar features of the landscape. "The first certain token of volcanos having existed in this country" became evident when he noticed new paving in the palace of the Elector-palatinate at Dusseldorf "with a lava exactly like that of Etna and Vesuvius". At the gates of Cologne "I was struck with the sight of numberless basaltic columns inserted in the walls of the town". Many of the older buildings in Cologne "were of a tuffa exactly resembling that of Naples and its environs". All these building stones had been obtained from local quarries. Sir William was alerted: "these circumstances made me keep a sharp lookout, and, on my approach to Bonn, was struck with the volcanic forms of the Sevenbergen, or Seven Mountains, about two leagues from the town, on the other side of the Rhine". A visit to three of the Sevenbergen and inspection of their craters and rocks confirmed their volcanic origin. He also recognised a number of basaltic lava flows. "I have not the least doubt but that all basaltes, wheresoever they exist, have originated from subterraneous fire and are true lavas." (*Phil. Trans.* v. 68, 1778, pp. 1-6.)

VOLCANOES AND EARTH HISTORY

Volcanism was not regarded as a significant factor in earth history in the late seventeenth century. Dr Martin Lister summarised the prevailing attitude.

That these Vulcanos were naturally kindled of themselves at or near Creation is probable, because there is but a certain known number of them, which have all continued burning beyond the memoirs of any Historie, few or none of them that I know of, have ever totally decay'd or been extinct, unless possibly by the submersion of the whole, being absorpt in the sea. Though they indeed do burn more fiercely sometimes then at others for other reasons. So that it seems to me as natural to have actual fire in the Terrestrial World from the Creation, as to have Sea and Water. *(Phil. Trans* No. 157, 1684, p. 516.)

The question of the significance of volcanoes in mountain building was related to interpretations of the nature of the interior of the earth. Athanasius Kircher, in his *Mundus Subterraneus* (1665) described the "fire cells throughout all the bowels of the Geocosm, the wonderful handiwork of God", and included a diagram showing an "Ideal System of Subterranean Fire Cells from which Volcanic Mountains arise, as it were, like vents". (Mather and Mason, 1939: pp. 17-9.) Kircher's ideas on volcanism and the nature of the earth's interior were developed from a trip to Calabria, Sicily and the Lipari Islands in 1636, and a subsequent visit to Vesuvius. His book was favourably reviewed in the *Philosophical Transactions* (No. 6, 1665, p. 109).

He affirms not onely to have explicated the Divine Structure of the Underground World, and the wondrous distribution of the Work-houses of Nature, and her Majesty and Riches therein; but also to have opened the Causes of her Effects and Productions . . .

Perhaps the writer of the reports on the volcanoes of the Moluccas was thinking of Kircher's fire cells when he noted that these were not local fires. The burning was continuous, even though no smoke was seen between eruptions

because the inward noise is so terrible that any person whosoever hears it, would judge with me that it is a bottomless Pit of the Vehementest Fire, which cannot be quenched while the World lasts. (*Phil. Trans.* No. 216, 1695, pp. 42-8.)

In a flight of speculation rare among reports of volcanic activity of the time, the same observer hinted at the possibility of more widespread geologic change through volcanism:

it seemeth evident that in those Parts and Seas, there are Subterraneous Fires, having a mutual Communication one with another: which God knoweth but may some time cause the sudden subversion of them and consequently a notable Change or Alteration of the World's Globe. (*Phil. Trans.* No. 228, 1697, pp. 529-32.)

Despite theories of an originally molten earth propounded by continental writers such as Descartes and Leibnitz, and the deep seated fire cells postulated by Kircher, English scientists inclined more toward the home grown theories of Burnet, Whiston and Woodward which relied largely on Noah's Flood as the chief sculptor of land forms. Volcanoes were regarded as strictly local, superficial, albeit spectacular, phenomena. During the eighteenth century a good deal of field evidence, particularly that relating to the occurrence of fossils, was accumulated and cast grave doubts on the Deluge hypothesis for the shaping of all land forms. It was also becoming increasingly obvious that the orthodox chronology of 4004 B.C. for the Creation and 2348 B.C. for the Deluge was too short to account for many observable geologic changes. (Stokes, 1969.)

Continental writers felt less constrained by the scriptures. Anton Lazzaro Moro's suggestion that all land forms had been produced by the action of subterranean fires was at the opposite extreme to formation during the Deluge. His book *De Crostacei e degli altri marini Corpi che si truovano su Monti* (Venice, 1740) was duly reviewed in the *Philosophical Transactions*. The chief concern of the reviewer was not Moro's theories of mountain building but his ideas on the formation of fossils, a topic of perennial interest to members of the Royal Society. Moro "has adopted a new system concerning marine Petrification, the Cause of which he refers to Fire instead of Water". Moro had developed his ideas from accounts of the eruptions at Santorini in 1707, the formation of the volcanic cone at Pozzuoli, near Naples in 1538, and the continued eruptions of Vesuvius and Etna. Although Moro refuted the theories of Burnet and Woodward he did not entirely dispense with Noah's Flood and "Lays down a fundamental Maxim that the Deluge ought to be believed according to the Scripture, as a Miracle, and not to be proved by Natural Rules". (*Phil. Trans.* No. 479, 1746, pp. 163-6; see also Adams, 1938: pp. 365-72 and Geikie, 1905: pp. 61-5.)

The Comte de Buffon's theory of the earth envisaged the gradual cooling of an incandescent globe over the period of approximately 75,000,000 years divided into six "epochs". Despite this concept of an originally molten earth, paradoxically, Buffon also regarded volcanoes as purely local, superficial phenomena. In the Fourth Epoch the waters which had condensed on the cooling surface of the earth withdrew and the volcanoes became active. Fragments of material including vegetable matter, salts, pyrites, bitumens, were "carried down and deposited in the low places and in the fissures of the rock of the globe where, finding substances already sublimated by the great heat of the earth, they formed the essential material for the alimentation of the volcanoes . . ." Actual eruptions Buffon considered were caused by "the effervescence of the combustible and pyrite bearing stones" when brought into contact with a sufficient quantity of water. For this reason volcanoes were located on islands or on the sea coast. (Mather and Mason, 1939: pp. 58-73; Geikie, 1905: pp. 88-97.)

Buffon's ideas became well known in England but English theorists were reluctant to part with the Deluge hypothesis and the orthodox chronology of earth history, especially as an explanation of fossils. Edward Wright wrote: "To account for these phenomena, I believe Mons. de Buffon must admit a universal deluge, such as is related in the Holy Scripture". (*Phil. Trans.* v. 49, 1755-6, pp. 670-2.) Sir William Hamilton took issue with Buffon's ideas on the local nature of the distribution of volcanoes. He provided the Royal Society with accounts of the formation of the volcanic cone at Pozzuoli in 1538:

an instant of a mountain of considerable height and dimensions, formed in a plain, by mere explosion, in the space of forty eight hours. The earthquakes having been felt at a great distance from the spot where the opening was made, proves clearly, that the subterraneous fire was at a great depth below the surface of the plain; it is as clear that those earthquakes and the explosions proceeded from the same cause, the former having ceased upon the appearance of the latter.

Hamilton regarded this as ample evidence to dispute opinions of the local nature of volcanic activity

Does not this circumstance evidently contradict the system of M. Buffon, and of all the natural historians, who have placed the seat of the fire of volcanos towards the centre or near the summit of the mountains which they suppose to furnish the matter emitted? Did the matter which proceeds from a volcano in eruption come from so inconsiderable a depth as they imagine, that part of the mountain situated above this supposed seat of fire must necessarily be destroyed, or dissipated in a very short time: on the contrary, an eruption usually adds to the height and bulk of a volcano, and who, that has had an opportunity of making observations on volcanos does not know, that in the matter they have emitted for many ages, in lavas, smoke, ashes, etc., could it be collected together, would more than suffice to form three such mountains as the simple cone or mountain of the existing volcano? With respect to Vesuvius this could be plainly proved . . .

Sir William had already demonstrated the relationship of the modern Vesuvius to the more ancient volcano of Mount Somma.

Another proof that the real seat of the fire of volcanos lies even greatly below the general level of the country whence the mountain springs, is, that was it only at an inconsiderable depth below the basis of the mountain, the quantity of the matter thrown up would soon leave so great a void immediately under it, that the mountain itself must undoubtedly sink and disappear after a few eruptions. (*Phil Trans.* v. 61, 1771, pp. 29-30.)

Sir William did not appreciate the formation of a caldera and based his observations on the area around Naples. It is a pity he never visited Santorini. However, he had read Father Goree's account of the 1707 eruption and this confirmed his belief that many of the islands near Naples, and the Aeolian and Lipari Islands had a similar origin from the sea. He also quoted accounts of similar phenomena from Pliny and Strabo.

I have scarcely a doubt left with respect to the country I have been describing having been thrown up in a long series of ages by various explosions from subterraneous fires. Surely there are at present many existing volcanos in the known world; and the memory of many others have been handed down to us by history. May there not therefore have been many others of such ancient dates as to be out of reach of history? (*Phil Trans.* v. 61, 1771, pp. 38-9.)

In 1767 Sir William had written of a collection of specimens of rocks from around Vesuvius that he had sent to the British Museum:

I am well convinced by this collection, that many variegated marbles, and many precious stones, are the produce of volcanos; and that there have been volcanos in many parts of the world, where at present there are no traces of them visible. (*Phil. Trans.* v. 58, 1768, p. 12.)

Jean Etienne Guettard had recognised the true nature of the extinct volcanoes of the Auvergne in 1751. He reported his conclusions to the French Academy of Science the following year and these were published in the *Memoirs* of the Academy in 1756. Nicholas Desmarest confirmed Guettard's conclusions and added the important observation of the volcanic origin of basalt in 1763. (de Beer, 1962; Geikie, 1905: pp. 105-75.) Sir William Hamilton, on the basis of his field work in Italy, seems to have reached similar conclusions independently. (Sleep, 1969: p. 324.) Sir William was certainly the first to recognise the ancient volcanic origin of land forms along the Rhine Valley near Bonn.

Sir William Hamilton's observations in the field had led him first to consider the ages of Vesuvius and Etna.

For two or three miles round the mountain raised by this eruption all is barren, and covered with ashes; this ground as well as the mountain itself, will in time certainly be as fertile as many other mountains in the neighbourhood, that have been likewise formed by explosion. If the dates of these explosions could be ascertained it would be very curious, and mark the progress of time with respect to the return of vegetation, as the mountains raised by them are in different states; those (which I imagine to be the most modern) are covered with ashes only; others of an older date with small plants and herbs and the most antient, with the largest timber trees I ever saw; but I believe the latter are so very ancient as to be far out of the reach of history. (*Phil. Trans.* v. 60, 1770, p. 7.)

Sir William also considered the formation of soil as a factor in determining the age of lava flows and ash deposits. "Over the stratum of pumice and burnt matter that covers Pompeii, there is a stratum of good mould, of the thickness of about two feet and more in some parts . . ." The foundations of Pompeii were "in a deep stratum of lava and burnt matter" indicating earlier eruptions than the first recorded eruption of Vesuvius in 79 A.D.

The growth of soil by time is easily accounted for; and who, that has visited ruins of ancient edifices, has not often seen a flourishing shrub, in a good soil, upon the top of an old wall? . . . But from the soil which has grown over the barren pumice that covers Pompeii, I was enabled to make a curious observation. Upon examining the cuts and hollow ways made by currents of water in the neighbourhood of Vesuvius and of other volcanos, I had remarked that there lay frequently a stratum of rich soil, of more or less depth, between the matter produced by the explosions of succeeding eruptions; and I was naturally led to think that such a stratum had grown in the same manner as the one above mentioned over the pumice of Pompeii. Where the stratum of good soil was thick, it was evident to me that many years had elapsed between one eruption and that which succeeded it. I do not pretend to say that a just estimate can be formed of the great age of volcanos from this observation, but some sort of calculation might be made . . . Whenever I find a succession of different strata of pumice and burnt matter like that which covers Pompeii, intermixed with strata of rich soil, of greater or less depth, I hope I may be allowed reasonably to conclude, that the whole has been the production of a long series of eruptions occasioned by subterraneous fires.

The extent and source of each eruption could also be traced by field observation: "By the size and weight of the pumice, and fragments of burnt erupted matter in these strata, it is easy to trace them up to their source". (*Phil. Trans.* v. 61, 1771, pp. 5-6.)

While Sir William had made an enormous contribution to the advancement of volcanic studies, his teleology was reminiscent of the physico-theology of Ray and Derham earlier in the century.

Such wonderful operations of nature are certainly intended by an all-wise Providence for some great purpose. They are not confined to any one part of the globe, for there are volcanos existing in the four quarters of it. We see the great fertility of the soil thrown up by explosion, in part of the country I have described, which on that account was called by the ancients Campania Felix . . . May not subterraneous fire be considered as the great plough (if I may be allowed the expression) which nature makes use of to turn up the bowels of the earth, and afford us fresh fields to work upon, whilst we are exhausting those we are actually in possession of, by the frequent crops we draw from them?

He also commented on the precious minerals which "must have remained far out of reach, had it not been for such operations of nature". (*Phil. Trans.* v. 61, 1771, p. 39.) However, Sir William's plea for a more universal approach to the workings of natural phenomena was much more modern.

It is that we are too apt to judge of the great operations of nature on too confined a plan. When first I came to Naples, my whole attention, with respect to natural history, was confined to Mount Vesuvius, and the wonderful phenomena attending a burning mountain; but in proportion as I began to perceive the evident marks of the same operation having been carried on in the different parts above mentioned, and likewise in Sicily, in a greater degree, I looked upon Mount Vesuvius only as a spot on which nature was at present active, and thought myself fortunate in having an opportunity of seeing the manner in which one of her great operations (an operation, I believe, much less out of the common course than is generally imagined) was effected. (*Phil. Trans.* v. 61, 1771, pp. 39-40.)

Sir William Hamilton was convinced that the area around Naples "is wholly and totally the production of subterraneous fires" which erupted from below sea level and built up the land.

If I may be allowed to compare small things with great, I imagine the subterraneous fires to have worked in this country under the bottom of the sea, as moles in a field, throwing up here and there a hillock, and that the matter thrown out of some of these hillocks formed into settled volcanos, filling up the space between one and the other, has composed this part of the continent, and many of the islands adjoining.

The island of Sicily was even more interesting from a volcanological point of view.

The Kingdom of the Two Sicilies offers certainly the fairest field for observations of this kind, of any in the whole world; here are volcanoes existing in their full force, some on their decline, and others totally extinct. (*Phil. Trans.* v. 61, 1771, pp. 2-3.)

Not only did Sir William appreciate the uniformitarianism of the geological process he observed, but he also realised the vast expanse of time involved.

Nature, though varied, is certainly in general uniform in her operations; and I cannot conceive that two such considerable volcanos as Etna and Vesuvius should have been formed otherwise, than every considerable volcano of the known world. I do not wonder that so little progress has been made in the improvement of natural history, and particularly in the branch of it which regards the theory of the earth; nature acts slowly, it is difficult to catch her in the act. (*Phil. Trans.* v. 61, 1771, p. 2.)

Sir William Hamilton's appreciation of volcanic landscapes is perhaps best illustrated in his fine description of the view from the summit of Etna.

I counted from hence forty-four little mountains (little I call them in comparison with their mother Etna, though they would appear great any where else) in the middle region on the Catania side, and many others on the other side of the mountain, all of a conical form, and each having its crater; many with timber trees flourishing both within and without their craters. The points of these mountains, that I imagine to be the most ancient, are blunted, and the craters of course more extensive and less deep than those of the mountains formed by explosions of a later date, and which preserve their pyramidal form entire. Some have been so far mouldered down by time as to have no other appearance of a crater than a sort of dimple or hollow on their rounded tops, others with only a half or a third part of their cone standing; the parts that are wanting having mouldered down, or perhaps been detached from them by earthquakes, which are here very frequent. All however have been evidently raised by explosion; and I believe, upon examination, many of the whimsical shapes of mountains in other parts of the world would prove to have been occasioned by the same natural operations. I observed that these mountains were generally in lines or ridges; they have mostly a fracture on one side, the same as in the little mountains raised by explosion on the sides of Vesuvius, of which there are eight or nine. This fracture is occasioned by the lava's forcing its way out, which operation I have described in my account of the last eruption of Vesuvius. Whenever I shall meet with a mountain, in any part of the world, whose form is regularly conical, with a hollow crater on its top, and one side broken, I shall be apt to decide such a mountain's having been formed by an eruption, as both on Etna and Vesuvius the mountains formed by explosion are without exception according to this description. (*Phil. Trans.* v. 60, 1770. pp. 12-14.)

CONCLUSION

In view of the later controversy which rocked geological circles between Neptunists and Vulcanists, it is perhaps unexpected that the igneous origin of basalt, and the existence of ancient volcanoes which had wrought considerable changes in past landscapes, should have been accepted without challenge by members of the Royal Society in the 1770's. Thomas West, reporting on specimens of lava found in a "volcanic hill near Inverness" in Scotland, expressed surprise at "the little attention paid to so extraordinary a phenomenon, and which seems to prove beyond a doubt the existence of volcanoes in this country . . ." (*Phil. Trans.* v. 67, 1777, pp. 385-7.) The whole Neptunist-Vulcanist controversy, as Taylor (1969) has pointed out, was not a simple matter of the aqueous or igneous origin of basalt, but to some extent a matter of approach. The mineralogists, led by Werner, pushed the theory of an aqueous origin. Observers in the field had no difficulty in accepting the volcanic nature of basalt. Indeed, Werner's pronouncement of an aqueous origin of basalt in 1787, and uncritical acceptance by his disciples, only clouded an issue already abundantly clear to both French and English field observers. And Werner's explanation of volcanoes as modern, local phenomena arising from the spontaneous combustion of underground coal seams was merely a variant on ancient ideas of firing of subterranean combustible materials.

The tradition of field observation was strong in the *Philosophical Transactions* of the Royal Society and Sir William Hamilton's papers were among the finest examples of this. A curious mixture of modern field volcanologist and eighteenth century classical scholar and gentleman, imbued with teleological ideas of the physico-theologians, Sir William made a magnificent contribution to this tradition of field work and did more than anyone to develop a true appreciation of volcanism among English scientists.

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